TRANSPLANT ROOT GROWTH IN RELATION TO AGE, HANDLING, AND PRODUCTION SYSTEM IN TOMATO AND PEPPER

By

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Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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Tomato (Lycopersicon esculentum Mill.) and pepper (Capsicum annuum L.) transplants were evaluated on root growth, shoot growth, and fruit yield in response to production system, transplant age, storage, and exogenous ABA hormonal stress.

Containerized tomato transplants produced with overhead irrigation (SP1) maintained more uniform shoot and root growth during greenhouse production than those grown with sub-flotation (SP2) irrigation. When grown under severe water stress, growth of SP2 plants was arrested. However, SP2 transplants had earlier fruit yields than SP1 plants when stress was minimal in the greenhouse. Transplants outyielded direct-field seeded plants in fall and winter field planting, though no differences occurred in spring plantings.

Containerized 45-day-old tomato transplants that were pulled, packed, and stored at 5 and 15°C for 8 days had negative shoot and root growth changes compared to transplants kept in Speedling trays. When 35-day-old pulled transplants were stored at 20/28°C for 3 days, growth during storage and extra-large fruit production were negatively affected compared with transplants kept in trays. Plant growth was similar for 4-, 5-, and 6-week-old plants in the spring, while 5-week-old transplants had the most large fruit yield. In the fall, yields were similar among 2- to 5-week-old transplants.

Abscisic acid (ABA) depressed germination, impaired normal pepper seedling development, and reduced root growth when applied to the rooting medium. Applied onto leaves, ABA 10^{-4} M caused a transient leaf-weight-increase inhibition, more evident in seedlings grown under continuous rather than alternate watering. Root growth and subsequent fruit yields, however, were unaffected.

For peppers, SP1 transplants had greater basal root length than SP2 plants prior to planting. Transplants had a more uniform root growth than direct-seeded plants which had 18% of the total root mass allocated to taproot. Spatial root distribution was greatest in the upper 0-10 cm soil level for all treatments. The coordination of growth between roots and shoots changed after fruit set in

transplants. The transplants exhibited more fruit production and greater fruit sink than seeded plants.

CHAPTER 1

INTRODUCTION

Tomato (Lycopersicon esculentum Mill.) harvested from 27,600 ha is the most important fresh-market vegetable crop in Florida with a farm value in 1988-1989 of 657 M dollars. As such, it represented 42.7% of the total vegetable output of 1,540 M dollars. Pepper (Capsicum annuum L.) ranks as the number three vegetable crop in Florida with a farm value in 1988-1989 of 110 M dollars, 7.2% of the total farm value, and harvested from 9,500 ha (Florida Agricultural Statistics, 1990).

Tomatoes are established either by direct-seeding or transplanting. Direct-seeding is done through polyethylene mulch using a plug-mix seeding method (Hayslip, 1974). Transplanted crops are mainly established from containerized transplants grown in greenhouses using multicellular trays (Hochmuth, 1988a). Direct-seeding can result in slow, variable, and low plant stands when extremes high or low temperatures, water stress or heavy rains, and the presence of soil-borne pests and diseases at the time of planting (Heydacker and Coolbear, 1977). Transplanted plants are more uniform, can better tolerate or escape early stresses,

and can achieve earlier crops than direct-seeded plants (Weaver and Bruner, 1927; Liptay et al., 1982). The choice of a particular system depends on the economics of plant establishment, on the performance of the plant after establishment, and on the value of the subsequent yield.

Plant productivity depends on the rapid development and growth of an adequate root system. Roots absorb and translocate water and nutrients, serve as sink and storage for carbohydrates, synthesize hormones and organic compounds, and support the plant (Miller, 1986). In most plant species, root mass consists of 10-20% of the mature plant biomass and is allocated to (a) taproot or radicle, of embryonic origin; (b) lateral roots arising from the pericycle; and (c) adventitious roots arising from non-root tissues (Esau, 1965; Zobel, 1986). In tomatoes and peppers, root mass is also allocated to basal roots arising from the lower region of the hypocotyl (Stoffella et al., 1988b; Zobel 1975).

Root orientation and root branching patterns are affected by the physical and chemical characteristics of the soil or other medium in which the roots are growing (Feldman, 1984). Stresses originating in the root zone, such as depletion of water, oxygen, or nutrients, or mechanical impedance, are directly sensed by the shoots. This affects dry matter partitioning between roots and

shoots, and hence the productivity of the plant (Brouwer and de Wit, 1969).

Brouwer (1963) described the functional equilibrium between root and shoot as an interrelated growth, in which significant changes in the rate of shoot growth are transmitted to the roots thereby affecting the rate of root growth; likewise, changes in the rate of root growth affect the rate of shoot growth. Pearsall (1927) described the coordination of growth as the close relationship between the size of the shoots and roots. Linear relationships usually are found between shoots and roots during vegetative growth; however, changes occur during the transition to reproduction (Brown and Scott, 1984). Russell (1977) considered growth as the relationship between 'sources' (the photosynthesizing leaves and absorbing roots) and 'sinks' (the growing tissues). The maintenance of a constant 'source-sink' relationship is comparable to a close coordination between shoot and root growth.

Yields are mainly determined by early growth events (Thome et al., 1982). Therefore, it is important to understand how dry matter partitioning patterns are established, maintained, or modified throughout the vegetative phase. Investigations on early growth changes of containerized transplants and direct-seeded plants, and the relationship of those changes with fruit yield are minimal

The objectives of this research were to (a) determine the effects of transplant production system and direct-seeding method on early growth and subsequent yield of tomato and pepper; (b) investigate the major growth and developmental changes in tomato as affected by age and storage; and (c) determine the effects of water and hormonal stress on root and shoot growth, and morphology, of pepper seedlings.

CHAPTER 2

ROOT AND SHOOT GROWTH AND DEVELOPMENT IN RELATION TO FRUIT YIELD FOR TOMATO TRANSPLANTS

Introduction

Fresh market tomatoes (Lycopersicon esculentum Mill.) are established in the field by transplants or direct seeding. Most transplanted tomatoes in Florida are now established with containerized transplants, which are previously grown in greenhouses in multicellular trays (Hochmuth, 1988a). In the greenhouse, containerized transplants are subjected to water, fertilizer, light, and air temperature stress which may cause structural and/or physiological changes during early root and shoot development (Feldman, 1984). In the field, transplants develop a dense root system promoted by early modification of the taproot and development of basal and lateral roots (Stoffella, 1983), while direct-seeded plants develop a strong taproot (Weaver and Bruner, 1927).

Containerized transplants have higher plant survival, faster re-establishment, and improved plant uniformity than seeded plants (McKee, 1981; Nahrung, 1984). The major benefit of transplants is earlier maturity (Waston and Zandstra, 1989; Dufault and Melton, 1990). In addition, the

use of transplants allows more efficient use of land than direct seeding. Similar advantages were also reported for bareroot transplants (Liptay et al., 1982).

Transplant condition or quality at time of planting is influenced by root-container size (Knavel, 1965; Weston and Zandstra, 1986), transplant nutrition (Jaworski and Webb, 1966, Jaworski et al., 1967; Widders, 1989), transplant age (Chipman, 1961), and transplant storage (Thomas and Moore, 1947). Transplant quality at time of planting also affects stand establishment, fruit size, and fruit yield (Chipman, 1961; Nicklow and Minges, 1962; Weston and Zandstra, 1989). Larger transplants produced earlier yields; however, more labor was required to handle the plant, and therefore production costs were increased (Van Vooran et al., 1986).

Speedling Inc. (Sun City, Fla.), a major supplier of greenhouse containerized tomato transplants in the U.S. (Weston and Zandstra, 1986), produces transplants with either overhead (SF1) or sub (flotation) (SF2) irrigation. In the first system, transplant trays are suspended on wires 1.5 m above the floor and irrigated overhead (until water drains from the bottom of the tray). In the second system, transplants are suspended on metal wires and irrigated by a flotation system in which water moves upward via capillarity to the surface of the cell (Seirenger and Boetdorff, 1989). During transplant production, cell moisture control has been considered one of the key factors affecting transplant

condition (Nahrung, 1984). Sub-irrigation appear to be important for improved uniformity and quality of grass seedlings (Howard and Watschke, 1984) However, it is not known how overhead and sub-irrigation systems will affect the transplant condition and dry matter distribution prior and subsequent to field transplanting under different environments.

Three experiments were performed to (a) characterize transplant growth prior to, during, and after field transplanting, (b) determine the relationships of early growth characteristics to fruit yield; and (c) compare growth from plants established by direct-seeding and transplanting.

Materials and Methods

Fall 1987 Transplant Production

Transplants were grown with overhead irrigation (SF1) at Speedling, Inc. in standard plastic greenhouses in Sun City, Fla. (Lat. 27.4 °N and Long. 82.3 °W). Speedling polystyrene trays with 96 inverted pyramid cells of 4.5 cm x 6.4 cm (side length x depth) and 39.5 cm^3 volume were used for growing the transplants. 'Sunny' tomato seeds were sown in a peat-vermiculite-perlite mix (2:1:1, v/v/v) on 29 June 1987. Trays were transferred to germination chambers at 25 °C and 100 % RH for 3 days, and then to the greenhouses where they remained for 35 days until transplanting.

Seedlings were watered daily by gravity using an automatic irrigation boom. Soluble fertilizer (20N-10P-20K) at a concentration of 50 to 100 mg $N\,l^{-1}$ was given every two days after seedling emergence. Fertilizer and water were withheld during the last two days before field transplanting for acclimation. During the seedling-growth period maximum/minimum air mean temperatures were 33/23 °C, respectively, and maximum/minimum greenhouse temperatures were 42/18 °C, respectively.

Transplants with floatation irrigation (SP2) were grown in fully automated plastic greenhouses in Bushnell, Fla. (Lat. 28.4 °N and Long. 82.5 °W). This facility was located at an isolated area from commercial tomato fields to minimize plant exposure to bacterial leaf spot disease. Tomato seeds were sown on 29 June 1987. After germination, trays were transferred to greenhouses where they were suspended on metal wires 20 cm above concrete floors. Every two to three days, the irrigation-water level was raised to the level of the container, maintained for 30 min, and then lowered to the original level until the next irrigation. Fertilizer was applied similarly to the SP1 transplants. Fertilizer and water were withheld for six days prior to field transplanting, for acclimation. During the seedling growth period, maximum/minimum air mean temperatures were 33/21 °C, respectively, and maximum/minimum greenhouse temperatures were 40/21 °C, respectively.

Fall 1987 Field Experiments

Transplants were established at a commercial farm located in Parrish, Fla. (location No. 1) on a sandy soil (sandy, siliceous, hyperthermic, Alfic Haplaquods) on 2 Aug. 1987. Raised beds, 0.2 m in height were spaced 1.8 m apart with each bed 0.6 m wide. Plants, on single rows, were spaced 0.6 m apart within the bed. Fertilizer (30N-270P-60K kg·ha^{-1}) was broadcast and incorporated into the center of the bed. Topdress fertilizer (225N-450K kg·ha^{-1}) was applied in two bands in shallow grooves on the bed surface, 25 cm to each side of the bed center. Beds were fumigated with methyl bromide-chloropicrin (67:33) at 220 kg·ha^{-1} and covered with white polyethylene mulch (0.038-mm thickness). Seepage irrigation was applied to maintain a uniform level of moisture, with the water table about 40 cm below bed surface. Seepage-irrigation ditches were located between every 3 beds. Plants were staked every 0.6 m and tied 4 times. Standard pesticides and cultural practices were used (Hochmuth, 1988a).

Transplants were also established at a commercial farm in Bradenton, Fla. (location No.2) on a sandy soil (sandy, siliceous, hyperthermic, Entic Haplaquods) on 2 Aug. 1987. The same cultural practices as for location No.1 were used, with the exception that the raised beds were 0.15 m in height, fertilizer was broadcast at a rate of 26N-108P-40K kg·ha^{-1}, topdress fertilizer was applied at a rate 300N-480K

kg·hs^{-1}, seepage-irrigation ditches were located every four beds and plants were staked every 1.2 m and tied three times.

At both locations, samplings of whole plants (1/plot) were initiated at the time of transplanting and continued weekly for 28 days after transplanting (DAT). Root samples were shovel-excavated at 20 x 20 cm (side x side) from the center of the plant, to the 30 cm depth. Plants were first gently shaken, grasped by the stem, placed in polyethylene bags and transported to cold rooms at 5 °C, where they remained for one to three days until examined. Shoots were excised at soil level. Stem diameter (SD) was measured with a digital caliper just below the cotyledonary node. Stem length (SL) was measured from the shoot apex to the cut end. Leaf number (LN) (>1 cm in length) and leaf area (LA) (LI-COR Leaf Area Meter, Model LI-3100) were measured. Plants were soaked in water and the roots were collected from the medium by washing on a 1-mm-mesh screen. The washed roots were blotted and root volume (RV) estimated by water displacement (Bohm, 1979). Plant material was oven-dried at 65 °C for 3 days and dry weights of shoots (leaves+stems) (SDW) and roots (RDW) were recorded and shoot:root ratios (S:R) calculated. Fruits were harvested at the mature green stage from 25 plants per plot on 23 Oct., 7, and 23 Nov., 72, 87, and 103 days after transplanting, respectively. Fruits were graded by diameters (USDA, 1976) into medium

(57-65 mm), large (65-70 mm), and extra large (> 70 mm) sizes, counted, and weighed. Misshapen, diseased, or undersized (< 57 mm) fruits were considered culls. A randomized complete block design with six replications for each treatment was used at sampling dates of 0, 7, 14, 21, and 28 days after planting. Each experimental unit consisted of 50 plants. Growth and fruit yield data were subjected to analysis of variance, with each sampling cluster partitioned into linear or quadratic orthogonal responses.

Spring 1988 Transplant Production

Transplants were grown with overhead irrigation (SP1) and flotation irrigation (SP2) at the same location as in Fall 1987. A third transplant production treatment was grown with flotation irrigation (SP3) in the same greenhouse location as SP1. 'Sunny' tomato seeds were sown on 1st. Jan. 1988 in Speedling polystyrene trays with 150 inverted pyramid cells of 3.8 cm x 6.4 cm (side length x depth) and 30.7 cm^3. Germination and transplant growing procedures were as described for location No.1, fall 1987, with the exception that the soluble fertilizer (20-10-20) was added at 10 to 80 mg $N \cdot l^{-1}$ for SP1 and SP2 and at 60 mg $\cdot l^{-1}$ for SP3 transplants. Irrigation was applied every 2 days until 40 DAS, and transplants were grown for 44 days. For SP2, at each irrigation water was pumped from a main reservoir into the greenhouse and, after 30 min of irrigation, returned

back to the main reservoir. Irrigation for SP3 transplants was done similarly as for SP2 transplants grown in fall 1987. Maximum/minimum mean air temperatures were 24/11 °C, respectively, in Bradenton (SP1 and SP3) and 19/7 °C in Humhnell (SP2) while the maximum/minimum in the greenhouse were 32/5 °C, respectively for both locations.

Spring 1988 Field Experiment

Transplants were established on 25 Feb. 1988 at the same location as site No.1 of fall 1987. Plant spacing, pesticides, and cultural practices were the same as for that location, with the exception that starter fertilizer was broadcast at 20N-80P-140K $kg \cdot ha^{-1}$, topdress fertilizer was applied at 232N-45OK $kg \cdot ha^{-1}$, and beds were mulched with black polyethylene. Whole plant samples were taken and tissue sampling was initiated 2 weeks before transplanting and continued weekly for 42 days. Plant samplings and measurements were performed similarly as in fall 1987. Fruits were harvested from 15 plants/plot on 19 May, 2, and 16 June, 85, 99, and 115 DAT, respectively.

A randomized complete block design was used with five replications for each treatment was used. Each experimental unit consisted of 25 plants and data analysis was as described for the fall experiments. Treatment means were separated by LSD test (0.05). In those cases where shoot and/or root growth was linear, the test of homogeneity of the regression coefficients ($P \leq 0.05$) was performed.

Winter 1988 Transplant Production

'Sunny' tomato seeds were sown on 7 Nov. 1988 in Speedling polystyrene trays with 200 inverted pyramid cells of 2.5 cm x 7.2 cm (side length x depth) and 18.8 cm^3. Germination and growing procedures for transplants with overhead irrigation (SP1) and flotation irrigation (SP2 and SP3) were similar as in spring 1988, with the exception of fertilizer rate and frequency. For SP1 plants fertilization (20-10-20) at 45 mg $N \cdot l^{-1}$ started at 12 DAS and continued every 2 days until 40 DAS. For SP2 plants, fertilization (20-10-20) at 50 mg $N \cdot l^{-1}$ started 20 DAS and continued every 3 days until 40 DAS. In SP3 plants, fertilization (20-10-20) at 60 mg $N \cdot l^{-1}$ started immediately after emergence and continued every 2 days until 42 DAS. During the growing period, maximum/minimum mean air temperatures were 25/13 °C at Bradenton (SP1 and SP3) and 24/10 °C at Buehnell, while the inside greenhouse maximum/minimum was 34/10 °C, respectively for both locations.

Winter 1988 Field Experiment

SP1, SP2, and SP3 transplants also were established at a commercial farm located in Naples, Fla. on a fine sandy soil (sandy, siliceous, hyperthermic, Alfic Arenic) on 21 Dec. 1988. A direct-seeding treatment was included. Coated seeds were sown at a rate of 4 seeds/drop in 60 ml of Metro-Mix, a peat-vermiculite soil amendment (Odell, 1986). Raised beds, 0.15 m in height, were spaced 1.8 m apart with

each bed 0.8 m wide. Plants on single rows were spaced 0.55 m apart within the bed with each plot consisting of 25 plants. Fertilizer (38N-202P-72K kg·ha^{-1}) was broadcast and incorporated into the center of the bed. Topdress fertilizer (235N-423K kg·ha^{-1}) was applied in two bands in shallow grooves on the bed surface, 20 cm to each side of the bed center. Beds were fumigated with methyl bromide:chloropicrin (67:33) at 392 kg·ha^{-1} and covered with black polyethylene mulch. Water table was maintained at the 30 cm below bed surface using seepage irrigation. Seepage irrigation ditches were located between every six beds, with plants being staked every 0.55 m and tied four times. Standard pesticides and cultural practices were used (Wochmuth, 1988a).

Whole-plant samplings were initiated two weeks before transplanting and continued weekly for 35 DAT. At planting (T0), one (T1), and two (T2) weeks after transplanting, roots were partitioned into three components: taproot, basal roots, and lateral roots (≥ 0.5 cm long). Root components were oven-dried at 65 °C for 3 days, and dry weights determined. Plant samplings and measurements were done as in Fall 1987. Fruits were harvested from 15 plants per replication on 16 March, 27 March, 12 April, and 25 April, 85, 96, 112, and 125 DAT, respectively.

On 25 April, root samples (1/plot) from half of the total plant root system were taken from SP1, SP2, and

direct-seeded plants, using a modified monolith pinboard (Bohm, 1979). A root sampler was constructed, consisting of a one-sided steel plate 50 X 30 cm (width x depth) and 0.5 cm thickness, with six rows of 30-cm-length nails of 0.5 cm diameter at 5 cm intervals (Fig. 2-1). Roots were sampled at three horizontal levels, 0-10 cm, 10-20 cm, and 20-30 cm, and in three vertical positions, 0-15 cm, 15-30, cm and 30-45 cm. A trench of 1.0 x 0.5 m (length x depth) was dug around the plant and after excavating the soil root sample, it was washed gently and roots were cut and separated from each horizontal and vertical section.

Spring 1989 Transplant Production

Transplant treatments and polystyrene trays were the same as for the spring 1988 experiment. 'Sunny' tomato seeds were sown on 12 Dec. 1988 and were grown for 43 days as previously described for the winter 1988 experiment. During the growing period, maximum and minimum mean air temperatures were 24/12 °C at Bradenton (SP1 and SP3) and 23/10 °C at Bushnell, while the inside-greenhouse maximum/minimum was 30/6 °C at Bradenton and 28/6 °C at Bushnell.

Spring 1989 Field Experiment

Transplants were established in spring 1989 at the location No.1, fall 1987 experiment. A direct-seeded treatment was included as previously described for the winter 1988 experiment. Fumigation, fertilization, and growing practices were the same as for the prior location.

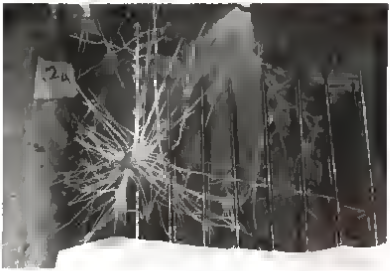


Fig. 2-1 Metallic monolith pinboard used for excavating the soil-root samples.
Top: Metallic pinboard being introduced into the soil-root sample.
Bottom. Washing the soil-root sample. Note the large basal roots in the top soil level.

Plant samplings and measurements were done as in fall 1987. Allometric models between root and shoot (leaves+stems) and between root and stem dry weights were determined. Slopes of the ln-ln were calculated and compared. Fruits were harvested from 10 plants per replication on 18 April, 2 May, 17 May, and 6 June 1988, 76, 88, 104,and 124 DAT, respectively. On 6 June 1988 root (1/plot) samples from SP1, SP2, and direct-seeded plants were taken in a manner similar to that for the winter 1988 experiment. Data analysis were done as in fall 1987.

Fall 1989 Field Experiments

SP1 and SP2 plants were grown as described for the spring 1988 experiment. 'Sunny' tomato seeds were sown on 12 July 1988, and plants were grown for 35 days. During the growing period, maximum/minimum air mean temperatures were 33/23 °C at Bradenton (SP1) and 32/21 °C at Bushnell (SP2), respectively, while the inside-greenhouse maximum/minimum was 36/18 °C at Bradenton and 35/16 °C at Bushnell, respectively.

Transplants and a direct-seeding treatment were established in the field on 16 Aug. 1988 in Parrish, Fla. at the same location as for the fall 1987 experiment. Plants were spaced 0.76 m apart within the bed, and cultural practices were the same as for this location. Fruits were harvested from 10 plants per replication on 30 Oct., 15 Nov , and 8 Dec., 75, 80, and 113 days after transplanting.

The same treatments as used at Parrish, Fla. were also established at a commercial farm in Bradenton, Fla. on 17 Aug. 1988. Preplant fertilizer (39N-100P-62K kg·ha^{-1}) and topdress fertilizer (216N-311K kg·ha^{-1}) were applied as before. Drip tubing, Netafim, was positioned 15 cm deep and 25 cm to the sides of the plants. Drippers were spaced 45 cm apart with a drip discharge rate of 2.25 l·h^{-1}. Irrigation kept the water table at 50 cm from the top of the bed. Plants were grown on single, raised (20 cm), beds covered with white polyethylene mulch (0.038 mm). The plants were spaced 1.8 m between rows and 0.5 m within rows. In both locations, experimental design and data analysis were performed as described before.

Results and Discussion

Fall 1987 Experiment

SP1 transplants had significantly larger leaf area and stem diameter than SP2 plants at Parrish, and similarly more leaves and larger stem diameters than SP2 plants at Bradenton (Table 2-1).

There was a significant transplant system x time interaction for leaf number (LN) and root volume (RV) at Parrish (location No.1) and for leaf area (LA) and RV at Bradenton (location No.2). At both locations, no difference between transplants occurred at T0 but, after two weeks, SP1 produced more LN and larger RV at location No.1 and more LA

Table 2 1 Effects of tomato transplant system on shoot and root growth

Parrish and Bradenton Florida Fall 1987

Source of variation	Leaf area (cm^2)	Leaf number (N_0)	Root volume (cm^3)	Stem diameter (cm)
Transplant System (TS)		*Parrish*		
SP1	300	7 0	2 3	6 7
SP2	240	6 4	1 3	6 0
	*	**	**	**
Time[z]				
T_0	32	4 9	0 8	3 8
T_1	111	6 8	1 3	4 4
T_2	823	9 5	4 0	8 2
T_3	-	-	-	12 1
T_4	-	-	-	13 8
Significance	Q**	Q**	Q**	Q**
		Interaction		
TS x Time	NS	**	**	NS
		Bradenton		
Transplant System				
SP1	198	6 7	1 6	6 5
SP2	147	6 4	1 1	6 1
	**	*	*	**
Time				
T_0	32	4 9	0 8	3 8
T_1	106	6 5	0 9	4 5
T_2	472	9 3	2 8	8 0
T_3	-	-	-	12 2
T_4	-	-	-	13 4
Significance	Q**	Q**	Q**	Q**
		Interaction		
TS x Time	**	NS	**	NS

[z] T_0 = time at initial transplanting, T_1, T_2 T_3 and T_4 are times 1, 2, 3 and 4 weeks after transplanting

NS, *, **Nonsignificant or significant F test at P = 0 05 or 0 01 respectively Significant time effects were quadratic (Q) or cubic (C)

and RV at location No 2 (data not shown). For many vegetable species, growth events are established early in development (Thomas et al., 1982) but can be modified by cultural practices. The morphological differences in favor of SP1 transplants were most probably established during early growth in the greenhouses, whereas SP2 transplants were subjected to severe water and fertilizer stress on a 'hardening' treatment before transplanting.

Transplant system (TS) x time interaction obtained for shoot dry weight (SDW), root dry weight (RDW), and shoot:root ratio (S:R) were partitioned over time (Table 2-2). At Parrish, SP1 had more SDW than SP2 transplants at T0 and T1, with no differences at T2 and T3. Also, SP1 had higher RDW than SP2 plants up to T2, with no differences thereafter. Shoot:root ratio increase was more uniform for SP1 than for SP2, which had a S:R increase up to 2 weeks with an abrupt decline at T3, and then an increase again at T4. Approximately similar RDW and S:R trends were found at Bradenton. The higher early root dry matter allocation for SP1 at T1 and T2 seems to be important for the subsequent SDW increase at T3 and T4. It appears that the size of a root system exerts some control over the size of the shoot system. These results agree with those from another tomato greenhouse study (Richards, 1981). SP2 transplants evidenced a delay in root growth, which may be due to the effects of root pruning and plant hardening. The S:R

Table 2-2 Effects of tomato transplant system on shoot and root growth dry weight Parrish and Bradenton, Florida Fall 1987

Transplant	Parrish					Bradenton				
System	T_0[z]	T_1	T_2	T_3	T_4	T_0	T_1	T_2	T_3	T_4
					Shoot wt (g)					
SP1	0.27	1.09	6.83	24.9	59.0	0.27	1.00	5.55	21.5	51.6
SP2	0.24	0.82	5.55	16.4	43.0	0.24	0.87	4.82	17.7	42.6
	**	**	NS	NS	*	**	*	*	**	*
					Root wt (g)					
SP1	0.07	0.14	0.55	1.9	3.7	0.07	0.10	0.39	1.3	2.6
SP2	0.06	0.10	0.34	1.7	2.8	0.06	0.08	0.28	1.4	2.6
	NS	**	**	NS	NS	NS	**	**	NS	NS
					Shoot-root ratio					
SP1	4.1	7.9	12.6	13.2	16.5	4.1	10.1	14.3	17.5	20.3
SP2	3.8	8.3	16.5	9.4	15.3	3.8	11.6	17.9	12.7	16.1
	*	NS	**	**	NS	*	NS	**	**	*

[z]T_0 = time of planting (35 days after seeding) T_1 T_2 T_3 and T_4 are times at 1, 2 3, and 4 weeks after transplanting

NS, *, **Nonsignificant or significant F-test at P = 0.05 or 0.01 respectively

alteration of SP2 plants could occur as a response to maintain a constant internal nutrient and/or water status (Richards, 1977), which is associated with the difference between the water transpired from the leaves and the water absorbed by the roots.

SP1 had more fruit yield than SP2 transplants (Table 2-3). SP1 transplants had 33% and 24% more extra-large fruits at the early harvest, 27% and 46% more total fruits at the second harvest, and an average of 29% and 41% more total marketable fruit yield than the SP2 transplants, at locations No.1 and No.2, respectively.

The results of these experiments indicate that the initial condition of the transplants affects subsequent root, shoot and fruit growth and yields.

Spring 1988 Experiment

Since significant transplant system x time interactions were obtained for LA, RV, and SDW, main effects were analyzed for each time. At T0, SP3 had 36% and 124% more leaf area than SP1 and SP2 transplants, respectively (Table 2-4). At planting, SP3 seedlings were tall and weak, probably as a result of high nitrogen and insufficient light due to plant to plant competition in the container. SP1 transplants had a linear LA increase and SP3 had an arrested growth after transplanting. RV increased linearly for all treatments, the linear slope of SP1 being higher than that of the SP2 transplants (Table 2-5). Similarly, SDW

Table 2 3 Effect of tomato transplant system on yields and fruit number/plant Location 1 (Farrlah) and 2 (Bradenton), Fall 1987

Location	Transplant system	Early[1] Extra-large	Early[1] Total	Mid Total	Late Total	Total
				Yield (t·ha^{-1})		
1	SP1	9 2	12 4	16 0	6 9	35 3
	SP2	7 0	10 4	12 6	4 3	27 3
		*	NS	**	NS	**
				Fruit number/plant		
	SP1	6 0	8 9	14 4	6 6	30 0
	SP2	4 0	7 3	10 6	3 4	21 3
		*	NS	**	NS	**
				Yield (t·ha^{-1})		
2	SP1	11 8	16 0	18 4	7 5	40 7
	SP2	9 6	13 8	12 6	3 7	29 4
		*	NS	**	*	**
				Fruit number/plant		
	SP1	6 9	10 6	16 4	7 6	34 5
	SP2	5 6	9 5	12 1	3 9	25 5
		*	NS	*	*	**

[1]Harvests were at 72 (early) 87 (mid) and 103 (late) days after transplanting. Extra-large fruits = > 70 mm diameter
NS, *, **Nonsignificant or significant F test at P = 0 05 or 0 01, respectively

Table 2-4. Effects of tomato transplant system on shoot and root growth, Parrish, Spring 1988

Transplant system	Time[a] T_2	T_1	T_0	T_1	Significance	r^2
			Leaf area (cm^2)			
SP1	24	33	41	51	L**	0.73
SP2	20	30	30	33	C**	0.41
SP3	32	47	61	56	C*	0.67
LSD (0.05)	2	3	5	8		
			Root volume (cm^3)			
SP1	0.33	0.37	0.61	0.71	L**	0.70
SP2	0.32	0.43	0.52	0.62	L**	0.57
SP3	0.34	0.37	0.56	0.68	L**	0.59
LSD (0.05)	--	0.05	0.08			
			Shoot weight (mg)			
SP1	99	176	248	297	L**	0.84
SP2	84	153	191	250	L**	0.72
SP3	107	176	275	320	L**	0.74
LSD (0.05)	12	20	26	49		

[a] T_2 and T_1 are 2 and 1 weeks before transplanting. T_0 = time of initial transplanting (44 days after seeding). T_1 = 1 week after transplanting.
*,**Significant F test at P = 0.05 or 0.01, respectively. Significant time effects were linear (L) or cubic (C).

Table 2-5 Slopes and slope-pairwise calculated t values for root volume and shoot weight as affected by tomato transplant system

Transplant system	b_1	Paired t values[z] SP1	SP2	SP3
		Root volume		
SP1	0 0153		2 632	0 838
SP2	0 0139			1 589
SP3	0 0174			--
		Shoot weight		
SP1	9 60	-	2 545	1.065
SP2	7 67			3 068
SP3	10 56			--

[z]Slope (b_1) coefficients are significantly different at P = 0 05 or 0 01 if paired t values are greater than 1 960 or 2 576 respectively

increased linearly for all transplants; however, the SDW slope for SP1 and SP3 was higher than that for the SP2 transplants (Table 2-5).

At 51 days after seeding SP3 plants had a higher (5.2) S:R ratio than SP1 (4.6) and SP2 (4.0) plants (Fig. 2-2). After 51 DAS, S:R ratio differences became less evident and were not significantly different after 58 days. The S:R decrease from 4.2 to 4.0 for SP2 seedlings before TO was due to both a SDW growth restriction and a RDW growth increase. SP2 plants had lower shoot and root dry weights than SP1 plants. The smaller plant size is a characteristic of hardened plants (Parkinson, 1952); however, Loomis (1925) reported that tomato plants hardened for 3 days increased carbohydrate reserves, which was beneficial for root growth regeneration. Similarly, some shoot-growth restriction was an advantage to avoid the excess growth that could cause fruit-set problems for tomato (Van Vooren, 1986). One hypothesis is that the restriction of root and shoot growth will reduce the assimilate used for these organs, increasing availability for development of the first inflorescence.

Fruit yields and fruit number/plant at each harvest were not significantly different among treatments (Table 2-6). Similar results were found when yields were pooled across harvests (Table 2-7) Although the size of the transplants (dry wt. basis) has been correlated with earliness (Van Vooren, 1986), in this experiment there were

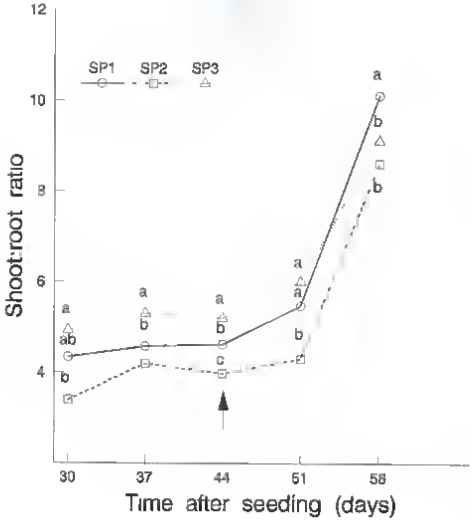


Fig. 2-2 Shoot.root ratio evolution of tomato transplants prior to and after transplanting Spring 1988. Means were separated by LSD (0.05).

Table 2-6 Effect of tomato transplant system on yields and fruit number/plant Parrish, Spring 1988

Transplant system	Early[a]				Mid				Late			
	Medium	Large	Extra large	Total	Medium	Large	Extra large	Total	Medium	Large	Extra large	Total
					Yield (t·ha^{-1})							
SP1	0 4	2 9	9 9	12 8	1 2	4 4	11 4	17 1	0 9	3 0	5 8	9 6
SP2	0 7	2 5	8 2	11 4	1 6	5 5	11 0	18 1	1 0	3 3	4 5	8 7
SP3	1 6	4 1	7 9	13 6	2 0	5 7	8 4	16 1	0 7	3 9	5 2	9 7
LSD (0 05)	--	--			0 5	--	--		--	--	--	--
					Fruit number/plant							
SP1	0 5	2 8	6 6	9 9	1 5	4 2	8 0	13 7	1 0	2 9	4 2	8 0
SP2	0 8	2 4	5 7	9 0	1 9	5 2	7 5	14 6	1 2	3 2	3 3	7 8
SP3	2 0	4 1	5 7	11 8	2 4	5 3	5 6	13 3	0 8	3 8	3 8	8 4
LSD (0 05)	--	--			0 6	--				--		

[a]Harvests were done at 85 (early), 99 (mid) and 115 (late) days after transplanting Fruit diameters were 57-65 mm (medium) 65-70 (large) and > 70 mm (extra large)

Table 2-7 Effect of tomato transplant system on total fruit yield and fruit number/plant Parrish, Spring 1988

Transplant system	Medium[a]	Large	Extra-large	Total
		Yield (t·ha^{-1})		
SP1	2.5	10.3	26.7	39.6
SP2	3.3	11.3	23.7	38.2
SP3	4.3	13.7	21.5	39.5
		Fruit number/plant		
SP1	3.0	9.9	18.8	31.6
SP2	3.9	10.9	16.6	31.4
SP3	5.2	13.2	15.1	33.6

[a]Fruit diameters were 57-65 mm (medium), 65-70 mm (large), and > 70 mm (extra large) Fruit sizes and total yield were pooled across all harvests Treatment effects were not significant

no advantages of using large transplants, such as SP3 plants, which are more likely to suffer from transplanting shock under severe field stress conditions such as drought or strong winds (Liptay, 1987).

Winter 1988 Experiment

SP1, SP2, and SP3 transplant shoot and root growth variables were similar, characterized by an early uniform increase up to T_{11}, followed by a fast increase thereafter (Table 2-8). The partitioning of root components indicated that SP2 and SP3 plants developed more taproot and lateral root growth than SP1 plants, which had more basal roots. This reaction appeared to be a developmental response to the differential water availability of the sub-flotation (SP2 and SP3) and overhead (SP1) irrigation system. For tomato, the ability to modify root morphology in response to different soil environments (Zobel, 1975) and water distribution (Cannell and Asbell, 1974) has been demonstrated. In the field after harvest, total root growth and root horizontal and vertical distribution were not significantly different between transplants and direct-seeded plants (Table 2-9). Although roots were not partitioned into their components, transplants appeared to have more and thicker basal roots than direct seeded plants (Fig. 2-3). For both transplant systems and seeded plants, approximately 72% of the total root mass was allocated in the upper 0-20 cm of the soil, probably by a greater

Table 2-8 Effects of transplant system on shoot and root growth

Naplam, Winter 1988

Source of variation	Leaf area (cm^2)	Stem length (cm)	Plant dry wt. Root (mg)	Plant dry wt. Stem (mg)	Plant dry wt. Leaf (mg)	Root components wt. Tap (mg)	Root components wt. Basal (mg)	Root components wt. Lateral (mg)	Shoot root ratio
Transplant System (TS)									
SP1	42	7 7	30	82	149	5	41	15	5 6
SP2	49	7 4	33	90	159	9	34	25	5 6
SP3	46	7 5	34	97	154	10	35	25	5 5
LSD(0 05)	--	0 2	--	--	--	2	--	8	
Time[a]									
T_{-3}	13	5 1	8	29	8	-			5 0
T_{-2}	15	5 4	16	54	19	--			4 6
T_{-1}	19	6 9	25	75	36	--	--	--	4 5
T_0	20	7 9	30	75	47	6	14	11	4 1
T_1	53	10 5	46	95	227	6	24	16	7 2
T_2	240	14 5	121	320	956	12	73	37	10 7
Signif	Q**	Q**	Q**	Q**	Q**	Q**	Q**	Q**	Q**
						Interaction			
TS x Time	NS	**	NS	NS	NS	NS	NS	NS	**

[a] T_{-3}, T_{-2}, and T_{-1} are 3, 2, and 1 weak before transplanting T_0 = time of initial transplanting (45 days after seeding) T_1 and T_2 are 1 and 2 weeks after transplanting

*, **, Nonsignificant or significant F test at P = 0 05 or 0 01, respectively Significant time effects were quadratic (Q) or cubic (C)

Table 2-9 Means of horizontal and vertical root dry weight distribution of tomato plants established by transplants or direct seeding, Naples, Winter 1988

Root distribution	Root dry weight (g)[1]			
	SP1	SP2	Direct Seed	F-test
Horizontal				
0-10 cm	3.42	3.81	3.71	NS
10-20 cm	1.27	1.47	1.05	NS
20-30 cm	0.05	0.04	0.14	NS
LSD (0.05)	2.01	2.49	2.07	
Vertical				
0-15 cm	3.43	3.71	3.49	NS
15-30 cm	0.87	0.84	1.00	NS
30-45 cm	0.44	0.76	0.41	NS
LSD (0.05)	2.04	2.57	2.17	

[1]Based on 1/2 of total root system. The main sheet was located in the 0-10 cm horizontal and 0-15 cm vertical compartment. Root samples were taken 125 days after planting. SP1 and SP2 = transplants.
[NS]Nonsignificant

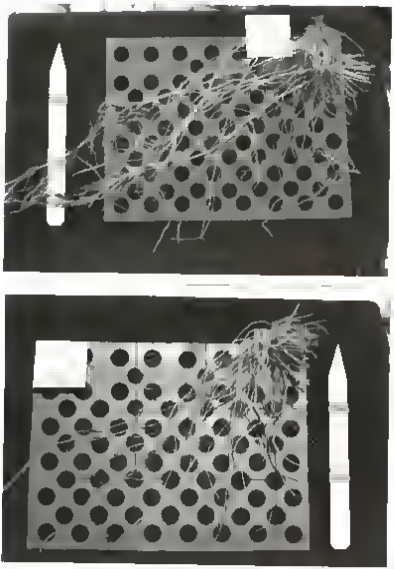


Fig. 2-3. Top. Root distribution of tomato transplants. Note the thicker and higher number of basal roots.
Bottom. Root distribution of direct-seeded plants. Note the high number of lateral roots.

contribution of basal roots as reported for field-grown tomatoes (Stoffella, 1983).

Partitioning of the significant transplant system x time interaction for S:R (Fig. 2-4) indicates that, between 23 (T_3) to 45 (T0) days after seeding, SP1 plants maintained about the same S:R up to transplanting compared to a more variable S:R for SP2 and SP3 plants.

Fruit sizes and number/plant were significantly different after the first harvest (Table 2-10). In early harvest, as expected, transplants had earlier and higher medium and large fruit yield that averaged 52 % more than that of direct-seeded plants. Although SP2 transplants had arrested shoot growth prior to transplanting (Fig. 2-4) due to plant acclimation, they also had 31% more large fruit number than SP1 transplants. A reduction in the growth potential of young shoots and roots was reported to decrease flower bud abortion and to therefore increase fruit set (Russell and Morris, 1983). At the third harvest, seeded plants had 120% more extra large fruits than the average yield of transplants, and 75% and 27% more large fruits than SP2 and SP3 plants, respectively. Total yields were not different between transplants (Table 2-11); however, transplants had more medium, large and total fruit yield and fruit number/plant than seeded plants.

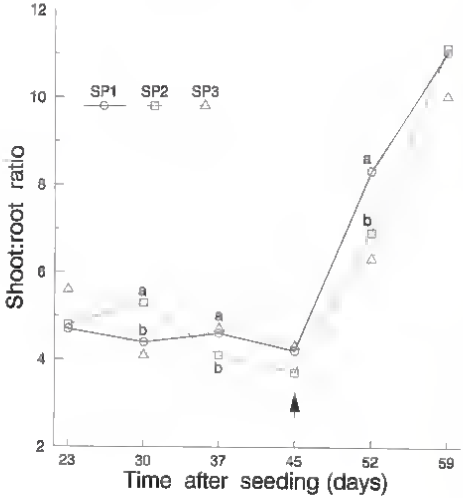


Fig. 2-4. Shoot:root ratio evolution of tomato transplants prior to and after transplanting. Winter 1988. Means were separated by LSD (0.05).

Table 2-10 Effect of tomato transplant system and direct seeding method on fruit yield and fruit number/plant Naples Winter 1988

Plant establishment	Early[a]				Mid				Late			
	Medium	Large	Extra large	Total	Medium	Large	Extra large	Total	Medium	Large	Extra large	Total
	Yield (t·ha^{-1})											
SP1	1 9	5 1	7 1	14 1	12 2	9 0	6 2	27 4	4 8	0 4	0 3	5 6
SP2	2 9	6 6	7 4	17 0	9 2	5 6	4 8	19 7	4 7	0 4	0 2	5 3
SP3	3 2	6 0	6 0	15 3	13 1	7 7	5 5	26 3	3 4	0 5	0 1	4 0
Seed	0 5	3 7	6 1	10 2	7 8	9 8	9 9	27 4	6 9	1 3	0 8	9 0
LSD (0 05)	1 1	1 4	--	3 6	4 4	2 0	2 2	6 3	1 7	0 5	0 4	2 3
	Fruit number/plant											
SP1	1 9	4 2	4 4	10 5	12 0	7 0	3 9	22 9	5 3	0 3	0 2	5 9
SP2	3 1	5 5	4 6	13 4	9 0	4 4	3 3	16 6	5 2	0 3	0 1	5 6
SP3	3 3	5 1	4 1	12 5	13 0	6 0	3 6	22 5	3 9	0 5	0 1	4 4
Seed	0 5	3 0	3 8	7 3	7 8	7 9	6 4	22 0	7 5	1 1	0 5	9 1
LSD (0 05)	1 1	1 2	--	2 6	4 4	1 6	1 6	5 9	1 7	0 5	0 3	2 1

[a]Harvests were at 96 (early), 112 (mid), and 125 (late) days after transplanting. Fruit diameters were 57-65 mm (medium) 65-70 mm (large), and > 70 mm (extra-large)

Table 2.11 Effect of tomato transplant system and direct seeding method on total fruit yield and fruit number/plant. Naples, Winter 1988

Plant[1] establishment	Medium	Large	Extra-large	Total
		Yield (t·ha^{-1})		
SP1	20.1	25.0	17.8	62.9
SP2	18.2	23.7	16.7	58.6
SP3	20.8	23.8	15.4	60.0
Direct seed	15.2	14.8	16.7	46.7
LSD (0.05)	5.2	2.6	---	8.3
		Fruit number/plant		
SP1	20.4	20.0	11.0	51.4
SP2	18.6	19.2	10.9	48.6
SP3	21.2	18.3	9.9	50.5
Direct seed	15.7	12.0	10.6	38.4
LSD (0.05)	5.3	2.1	-	7.3

[1]SP1, SP2, and SP3 = transplants. Fruit diameters were 57-65 mm (medium), 65-70 mm (large) and > 70 mm (extra-large). Fruit sizes and total yield were pooled across all harvests.

Spring 1989 Experiment

SP1 transplants had the highest SL, SD, and RDW (Table 2-12). The initial favorable shoot and root dry weight growth from SP1 transplants was not translated into superior root growth or root distribution in the soil, with SP1, SP2 and direct seeded plants having the same total root growth and vertical and horizontal root distribution (Table 2-13). All treatments allocated 68% of the total root growth to the upper 0-10 cm of soil, as measured at 124 days after planting.

All transplants evidenced, have a close in-in linear relationship between the roots and shoots (leaves+stems) and between roots and stems. Slopes of in-in regressions were similar with the exception that SP2 plants had a greater dry weight allocation to stems than did SP1 plants (Fig. 2-5). The greater stem dry weight increase for SP2 plants could be preliminary to the change in the pattern that characterizes flower initiation. Young tomato stems are the main vegetative organs, with the highest capacity to accumulate sugars before early fruit development (Tanaka et al., 1974).

SP2 plants had 50% higher total fruit yields and more fruit number/plant than SP1 and SP3 plants at the first early harvest (Table 2-14). At the second harvest all transplants had higher yields than direct seeded plants. Conversely, at the subsequent harvests, seeded plants had more fruit yield than did transplants. Therefore, the lack

Table 2 12 Effects of tomato transplant system on shoot and root growth Parrish, Spring 1989

Source of variation	Leaf area (cm^2)	Stem Length (cm)	Stem diameter (mm)	Root fresh wt (g)	Plant dry wt. Root (g)	Stem (g)	Leaf (g)	Shoot root ratio
Transplant system (TS)								
SP1	136	15 9	4 9	1 07	0 55	2 54	6 86	13.2
SP2	120	11 6	4 5	0.92	0.48	2 38	5 90	12 7
SP3	157	15.8	4 2	1.00	0 46	2 69	6 81	14 8
LSD (0 05)	-	0.7	0 5		0 07			1 2
Time*								
T_0	40	10 6	2 8	0 45	0 05	0 07	0 14	6 7
T_1	106	12 8	4 9	0 89	0 08	0 18	0 46	8.5
T_2	246	16 0	6 0	1 64	0 14	0 41	1 21	11.6
T_3		-	-	-	0 45	1 74	5 55	16 6
T_4		-		-	0 74	5 19	9 79	17 8
T_5	-				1 58	9 63	22 19	20 2
Significance	Q**	L**	Q**	Q*	C**	C**	C**	L**

*T_0 = time at initial transplanting (43 days after seeding) T_1, T_2, T_3, T_4, T_5 are 1, 2, 3, 4 and 5 weeks after transplanting

* **Significant F test at P = 0 05 or 0 01 respectively Significant time effects were linear (L) quadratic (Q), or cubic (C)

Table 2 13 Means of horizontal and vertical root dry weight distribution of tomato plants established by transplants or direct seeding Parrish Spring 1989

Root distribution	Root dry weight (g)[1]			
	SP1	SP2	Direct seed	F-test
Horizontal				
0 10 cm	5 13	4 71	4 62	NS
10-20 cm	1 20	1 15	0 94	NS
20-30 cm	1 21	0 56	0 50	NS
LSD (0 05)	3 04	2 74	2 77	
Vertical				
0-15 cm	4 90	4 31	4 28	NS
15-30 cm	1 49	1 40	1 11	NS
30 45 cm	1 15	0 71	0 68	NS
LSD (0 05)	3 10	2 87	2 88	

[1]Based on 1/2 of total root system The main shoot was located in the 0 10 cm horizontal and 0 15 cm vertical compartment Root samples were taken 124 days after planting SP1 and SP2 = transplants
[NS]Nonsignificant

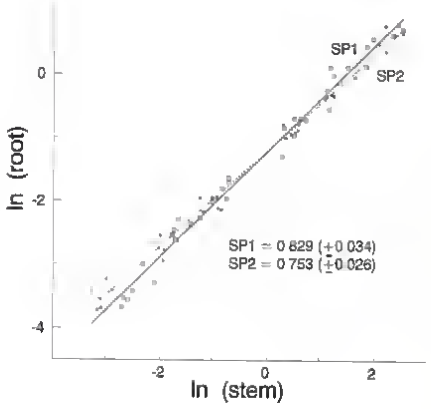


Fig. 2-5. Allometric relationship between root and stem dry weight for SP1 (solid line with squares) and SP2 (dotted line with asterisks) transplants. Values are slopes ± 95% confidence limits.

Table 2 14 Effect of tomato transplant system and direct seeding method on yields and fruit number/plant Parrish, Spring 1989

Plant establishment	Early[a] (1) Large	Extra large	Total	Early (2) Large	Extra large	Total	Mid Large	Extra large	Total	Late Large	Extra large	Total
						Yield (t·ha⁻¹)						
SP1	2 5	2 6	5 1	15 1	8 7	23 8	26 7	11 5	38 3	12 9	4 6	17 4
SP2	3 2	4 7	7 9	14 7	8 7	23 4	24 4	13 4	37 8	14 7	5 4	20 1
SP3	2 0	3 4	5 4	13 3	8 6	21 8	21 6	12 1	33 8	18 1	4 5	20 7
Seed	--	--	--	8 8	7 5	16 1	17 3	16 0	33 4	15 5	14 0	29 5
LSD (0 05)	0 7	1 2	1 6	2 7	--	3 5	3 5	4 2	--	--	3 8	5 9
						Fruit number/plant						
SP1	2 3	1 8	4 1	13 4	5 8	19 2	23 3	7 2	30 4	11 7	5 1	16 8
SP2	2 9	3 2	6 1	13 4	5 8	19 2	21 0	8 3	29 4	13 6	3 5	17 1
SP3	1 9	2 2	4 1	12 0	5 6	17 6	18 4	7 8	26 3	15 1	3 0	18 1
Seed	-	-	-	7 9	5 0	12 9	15 2	10 1	25 4	13 3	8 6	21 9
LSD (0 05)	0 7	0 8	1 1	2 5	--	3 0	3 6	2 5	4 6		2 3	4 6

[a]Harvests were at 76 (early 1), 89 (early 2), 104 (mid) and 124 (late) days after transplanting
Fruit diameters were 65-70 mm (large) and > 70 mm (extra large) SP1 SP2 and SP3 = transplants
Seed = direct seeding

of earliness for seeded plants was compensated with larger fruit yields than for transplants in later harvests, so that fruit yields were not significantly different among treatments (Table 2-15).

Fall 1989 Experiment

The SP2 transplants had greater LA and lower S:R ratio than SP1 transplants (Table 2-16). Transplants had similar growth responses over time, with the major increase between one and two weeks after transplanting. In Bradenton experiment, the significant transplant system x time interaction was partitioned for each time. Prior to transplanting SP1 had greater LA, SL, STDW, LDW, and S:R ratio than SP2 transplants, however, after transplanting, SP2 transplants had superior shoot growth to SP1 transplants (Table 2-17).

No differences occurred between transplants and locations for large and total fruit yield, and both transplants outyielded direct-seeded plants (Table 2-18). At Parrish, under seepage irrigation where water was constantly maintained in the field, transplants had more extra large fruit yield than direct-seeded plants. In the Bradenton experiment under drip irrigation, plants were subjected to short periods of water stress which effected fruit-size development and reduced the number of extra-large fruits (Table 2-19). Although drip irrigation is considered more efficient than seepage irrigation (Hochmuth et al

Table 2-15 Effect of tomato transplant system and direct seeding method on total fruit yield and fruit number/plant Parrish, Spring 1989

Plant[a] establishment	Large	Extra-large	Total
		Yield (t·ha^{-1})	
SP1	57 3	27 4	84 8
SP2	57 0	32 2	89 2
SP3	53 1	28 7	81 8
Direct seed	41 5	37 5	79 0
LSD (0 05)	8 2	7 1	--
		Fruit number/plant	
SP1	50 8	17 8	68 5
SP2	50 9	20 8	71 7
SP3	47 4	18 6	66 0
Direct seed	36 4	23 7	60 1
LSD (0 05)	7 4	4 3	8 9

[a]SP1, SP2, and SP3 = transplants. Fruit diameters were 65-70 mm (large) and > 70 mm (extra large). Fruit sizes and total yield were pooled across all harvests.

Table 2-16. Effects of tomato transplant system on shoot and root growth, Perrleh Fall 1989

Source of variation	Leaf area (cm^2)	Stem Length (cm)	Stem diameter (mm)	Plant dry wt. Root (g)	Stem (g)	Leaf (g)	Shoot root ratio
Transplant system (TS)							
SP1	124	12 8	4 0	0 06	0 23	0 88	10 4
SP2	139	10 4	4 0	0 08	0 25	0 78	8 3
Significance	**	NS	NS	NS	NS	NS	**
Time[a]							
T_{-1}	19	7 3	2 9	0 03	0 04	0 10	5 3
T_0	25	10 0	3 3	0 05	0 10	0 15	5 1
T_1	78	13 6	4 5	0 06	0 20	0 45	12 3
T_2	624	21 6	7 1	0 20	0 98	3 44	23 3
Significance	Q**	Q*	Q**	Q*	Q*	Q**	Q**

[a] T_{-1} = 1 week before transplanting T_0 = time of initial transplanting (35 days after seeding) T_1 and T_2 are 1 and 2 weeks after transplanting *TS x Time* interactions were not significant

NS, *, ** Nonsignificant or significant F-test at P = 0 05 or 0 01, respectively Significant time effects were quadratic (Q) or cubic (C)

Table 2-17 Effects of tomato transplant system on shoot and root growth Bradenton, Fall 1989.

Transplant system	Time[z] T_1	T_0	T_1	T_2	Significance	r^2
			Leaf area (cm^2)			
SP1	20	25	51	265	C**	0 97
SP2	17	25	62	409	C**	0 98
Significance	**	NS	NS	**		
			Stem length (cm)			
SP1	6 4	11 6	12 2	17 6	C**	0 93
SP2	6 2	6 6	12 2	18 0	Q**	0 97
Significance	**	**	NS	NS		
			Root dry weight (mg)			
SP1	27	46	54	127	Q**	0 81
SP2	27	53	62	184	C**	0 96
Significance	NS	NS	NS	*		
			Stem dry weight (g)			
SP1	0 05	0 11	0 15	0 46	C**	0 96
SP2	0-04	0 06	0 19	0 70	C**	0 97
Significance	**	**	NS	*		
			Leaf dry weight (g)			
SP1	0 12	0 17	0 31	1 57	C**	0 96
SP2	0-06	0 13	0 38	2 51	C**	0 98
Significance	**	**	NS	**		
			Shoot root ratio			
SP1	6 2	6 1	12 6	16 4	L*	0 36
SP2	4 4	4 0	9 2	17 5	Q**	0 96
Significance	**	**	NS	NS		

[z] T_1 = 1 week before transplanting T_0 = time of initial transplanting (35 days after seeding) T_1 and T_2 are 1 and 2 weeks after transplanting

NS, *, **Nonsignificant or significant F test at $P = 0.05$ or 0-01

Significant time effects were linear (L), quadratic (Q), or cubic (C)

Table 2 18 Effects of location and plant establishment on total fruit yields and fruit number/plant for tomato Fall 1989

Source of variation	Fruit yield (t·ha⁻¹)				Fruit number/plant			
	Medium[1]	Large	Extra large	Total	Medium	Large	Extra large	Total
Location (L)								
Parriah	6 3	29 7	9 8	45 8	7 0	24 2	5 5	36 8
Bradenton	8 2	29 3	5 2	42 8	8 3	22 6	2 7	33 7
Significance	NS	NS	**	NS	NS	NS	**	NS
Plant[2] establishment (PE)								
SP1	7 8	32 7	9 2	49 7	8 1	26 4	5 4	39 9
SP2	7 4	32 2	8 1	47 7	7 7	25 8	4 6	38 0
Seed	6 6	23 5	5 3	35 3	7 1	18 2	2 5	27 8
LSD (0 05)	—	4 9	2 5	6 0	—	3 8	1 2	4 9
				Interaction				
L x PE	**	NS	*	NS	**	NS	*	NS

[1]Fruit diameters were 57-65 mm (medium) 65 70 mm (large) and > 70 mm (extra large)
[2]SP1 and SP2 = transplants Seed = direct seeding
NS, *, **Nonsignificant or significant F test at P = 0 05 or 0 01

Table 2-19 Effects of location and plant establishment on medium and extra large fruit yields and fruit number/plant for tomato Fall 1989.

Plant[1] establishment	Fruit yield (t·ha^{-1})		Fruit number/plant	
	Medium[2]	Extra large	Medium	Extra-large
		Parrish		
SP1	5.1	13.0	5.7	7.7
SP2	5.8	10.7	6.4	6.1
Direct seed	6.3	4.4	7.1	2.2
LSD (0.05)		3.4	-	1.8
		Bradenton		
SP1	10.4	5.3	11.6	3.0
SP2	9.0	5.6	8.9	3.1
Direct seed	5.2	4.8	5.3	2.1
LSD (0.05)	4.0	-	3.9	--

[1]SP1 and SP2 = transplants
[2]Fruit diameters were 57-65 mm (medium) and > 70 mm (extra large)

1988), inaccurate application of water and emitter-clogging problems may hinder the beneficial effects. Transplants had higher yields than direct-seeded plants, since low temperatures limited plant growth and fruit yield potential of direct-seeded plants.

Results of field experiment demonstrated that transplant condition, which is directly related to the cultural practices and environment of transplant production, had the major influence on subsequent growth and development in the field. Initial fruit differences, as high as 41 % for SP1 plants in the fall 1987 experiment, were progressively reduced by adjusting and/or reducing fertilizer and water stress in the SP2 sub-flotation system.

For all seasons tested, SP1 transplants consistently maintained uniform root and shoot growth and higher shoot:root ratios than SP2 transplants. SP2 plants were generally subjected to a higher degree of stress than SP1 plants. Stress generally delays leaf enlargement, with stressed plants becoming smaller than unstressed plants (Boyer, 1968). SP2 transplants grown in fall 1987 under long-time-cyclic watering had small shoots, variable shoot:root ratios and a root-growth delay after transplanting. These responses appear to be characteristic for plants grown under the sub-flotation system. SP3 plants had generally larger leaf area and shoot:root ratios than SP1 and SP2 plants. Although higher shoots has been

considered an important indicator of a superior transplant, SP3 plants exhibited arrested growth after planting.

Early in development, in winter 1988, there was differential root-growth morphology among transplants. SP1 plants grown under overhead irrigation had more basal roots than SP2 and SP3 plants. For tomato, greater numbers of roots are associated with larger shoot growth rates (Richards, 1981). Conversely, SP2 and SP3 plants had greater development of lateral roots than SP1 plants. This response is probably due to the sub-flotation irrigation. Lateral roots, when grown under stress conditions, can be subjected to suberization and aging of root apicals, affecting the absorption and transport of nutrients such as Ca (Troughton, 1981). However, absorption of N, P, and K are more affected by root length rather than by root age (Russell and Clarkson, 1976). The root apical zone is also considered to be the site of most efficient water uptake.

The lack of significant difference between transplants and direct-seeded plants on total root dry matter allocation in the soil indicates that both had similar root growth capacity. Root dry weight for both transplants and direct seeded plants accumulated in the upper 10 cm of soil, probably due to the larger contribution of basal roots.

Fruit yield for SP2 plants was earlier than for SP1 plants in winter 1988 and spring 1989. Although higher shoot growth has been considered an important indicator of a

superior transplant, the lack of yield advantages of the large SP3 transplants, raised a question about the validity of that concept. Instead, uniform root and shoot growth prior to and immediately after transplanting seems to be of greater importance for subsequent plant growth.

Comparing plant establishment methods, transplants had higher total yield than direct-seeded plants in winter and fall. In those seasons, low temperatures have limited the yield potential of direct-seeded plants. Transplants exhibited earlier fruit yield than direct-seeded plants in winter, spring, and fall. However, in spring the lack of earliness in seeded plants was compensated by larger yields for transplants in later harvests. Direct seeded plants had similar or greater amounts of extra-large fruit size and lower large and medium fruit size than transplants in winter. However, in fall transplants had more extra-large fruits than direct-seeded plants at Parriah, where field conditions were considered near-optimal for plant growth. Therefore, transplants are recommended to be used in fall and winter. Direct seeding may be used in the spring if favorable environmental conditions are expected following planting.

Among transplants, SP2 plants grown under flotation are recommended if plants are subjected to minimal stress or hardening prior to transplanting. Excessive hardening has been reported to be detrimental for plant growth (Ruthatzky,

1986). SP2 plants may have low cumulative growth initially, however, they are more likely to survive and grow faster in the field than non-stressed, tall, and/or weak plants.

Cultural strategies that promote slow vegetative growth and improve root growth are needed to produce a high-quality transplant. Frequency of irrigation should be increased, watering times reduced and strength of nutrient solution kept to a minimum. Overwatering, or irregular watering and large doses of fertilizer (ie. greater than 100 mg of N/liter), should be avoided. Fertilization with calcium salts should be tested as well. Under sub-optimal post-planting conditions, stress resistance can be increased by slowly exposing seedlings to an increase of ventilation or mechanical stress that will promote stem strengthening (Heuchert et al., 1983; Jeffs et al., 1984). Minimal water stress can be used, but without allowing the roots to dry before transplanting. Prior to planting, transplants should be rewatered to obtain full turgor. The use of older transplants should be avoided and plant disturbance at pulling, packing, storing, and transplanting should be minimized.

Summary

Tomato cv. 'Sunny' containerized transplants produced with overhead (SP1) or sub-flotation (SP2 and SP3) irrigation, and direct-seeded plants, were evaluated on

growth and yield in fall, winter, and spring. Plant growth characteristics were measured weekly prior to, during, and after transplanting. SP1 plants had more uniform root and shoot growth and higher shoot:root ratios than SP2 plants, which were generally grown with a higher water stress than SP1 plants. SP3 plants with a higher initial shoot weight had a growth delay after transplanting. During early development, SP1 plants had more basal roots than SP2 and SP3 plants; however, total root dry weight was unaffected.

In fall 1987, SP1 plants had between 29 % and 41 % more fruit yield than SP2 plants. In winter 1988, fruit yields were similar for all transplants but higher than for direct-seeded plants. In spring 1989, total yields were unaffected, however, SP2 plants had earlier yields than SP1 and SP3 plants. In fall 1989, transplants had similar fruit yields but higher than those of direct-seeded plants. In general, transplants outperformed direct-seeded plants in fall and winter. SP2 transplants grown under the sub-flotation system can be used provided that the plants are grown with minimal stress prior to planting.

CHAPTER 3

GROWTH AND YIELD AFTER TRANSPLANTING AS INFLUENCED BY TRANSPLANT AGE

Introduction

In Florida, fresh market tomatoes are established in the field by direct seeding or by using 5 or 6 week-old containerized transplants. Plant performance after initial transplanting depends on the physiological stage of plant development, and on the environment. Containerized transplant age studies have been reported on several vegetable species. Lowest head weight variability was found for lettuce using 13 and 19 day-old transplants compared to 25 day-old transplants (Wurr and Fellows, 1986). Conversely, in a greenhouse experiment, earlier yields were obtained from 7 week-old lettuce transplants than from those 6 to 3 weeks old (Weng and Kretky, 1976). Yields were similar for 3 to 6 weak-old Chinese cabbage transplants grown in cylindrical cells of 50, 75, 100, or 150 ml (Kretky et al., 1982). Similarly, marketable curd yields did not differ between 5 to 8 week-old cauliflower transplants grown in cells of 14 ml (Wurr et al., 1986). Asparagus transplants that were 8.5 weeks old produced more shoots than those 6 and 7 weeks old, and were similar to 10

week-old transplants (Dufault and Waters, 1984). However, Burrows and Waters (1989) found superior growth for 11 week-old transplants. For pepper, 60 day-old seedlings had greater early yields than 30, 40, or 50 day-old seedlings (Weston, 1988) and 77 day-old seedlings had more fruit set than 56 day-old seedlings (McCraw and Greig, 1986).

For tomato, growth advantages of young roots, leaves, and plants were demonstrated in growth chamber and greenhouse experiments (Leonard 1962; Pest, 1970; Hurd and Thornley, 1974). In field experiments, plant growth improvement using younger bareroot transplants has been reported (Nicklow and Minges, 1962). Weston and Zandstra (1989), using containerized transplants, found that plant height, leaf area, and shoot weight increased uniformly as transplant age increased from 3 to 6 weeks, but measurements were performed only at transplanting. Larger early fruit yields were found for 3 to 5 week-old bareroot transplants as compared to 7 and 9 week-old transplants (Nicklow and Minges, 1962). However, none of these studies considered the changes in shoot and root development after initial transplanting. Such information would be useful in understanding the relationship between the physiological state of the transplants and their growth responses under different cultural systems and environments.

This study was conducted to determine the effects of transplant age (a) on growth after re-establishment and (b) on fruit size, fruit number, and fruit yield.

Materials and Methods

Transplant Production Spring 1988. Seedlings were grown in Speedling, Inc. greenhouse at Bushnell, Florida (Lat. 28.4 °N and Long. 82.5 °W). Speedling polystyrene trays, number 150, with 128 inverted pyramid cells of 3.8 cm x 6.4 cm (side length x depth) and 30.7 cm^3 volume were used for growing the seedlings. Tomato seeds were sown in a peat-vermiculite-perlite mix (2:1:1, v/v/v) on 19 Dec. and 26 Dec. 1988, and on 2 Jan. and 9 Jan. 1989, to obtain 3- (3W), 4- (4W), 5- (5W), and 6- (6W) week-old transplants. Trays were held in germination chambers at 25 °C and 100 % RH for 3 days, and then placed in the greenhouse where they remained until transplanting. After seedling emergence, transplants were irrigated three times/week for 45 min until 21 days, using a flotation system as described in Chapter 2. During each irrigation a soluble fertilizer (20-10-20) was applied at a concentration of 50 mg $N \cdot l^{-1}$. After 21 days seedlings (4W, 5W, and 6W) were irrigated twice/week for 30 min. For the last irrigation, seedlings were watered with the same nutrient solution and rate as had been used before. The greenhouse was held at 28 °C maximum and 6 °C minimum.

Transplant Production Fall 1989 Seedlings were grown in Speedling polystyrene trays, number 100A, with 200 inverted pyramid cells of 2.5 cm x 7.0 cm (side length x depth) and 18 cm^3 volume. Tomato seeds were sown on 15 July, 21 July, 28 July, and 4 Aug. 1989, for the 2-, 3-, 4- and 5-week-old transplants. After 5 days of seeding seedlings were irrigated for 30 min daily with a 20-20-20 (50 mg $N \cdot l^{-1}$) nutrient solution until 21 days using the same irrigation system used in spring 1989. After 21 days, transplants (4W and 5W) were irrigated three times/week for 30 min, and one day before delivery to the field with the same nutrient solution and rate used before. The greenhouse was held at 34 °C maximum and 18 °C minimum.

Experiment 1 Spring 1989 Transplants were planted at a commercial farm located in Parrish, Florida on a sandy soil (sandy, siliceous, hyperthermic, Entic Haplaquods) on 2 Feb. 1989. The transplants were 3 (3W), 4 (4W), 5 (5W) or 6 (6W) weeks old. Plants were grown on single raised (15-cm-high) beds spaced 1.8 m between rows and 0.6 m within rows. Fertilizer (26N-10P-42K kg·ha^{-1}) was broadcast and incorporated in the center of the bed. Topdress fertilizer (300N-48OK kg·ha^{-1}) was applied in two bands in grooves on the bed surface, 25 cm to each side of the bed center. Beds were fumigated with methyl bromide:chloropicrin (67:33) at 210 kg·ha^{-1}, and covered with black polyethylene mulch (0.038-mm thickness). Seepage irrigation was applied to

maintain a uniform level of moisture and a water table of about 40 cm in depth. Seepage irrigation ditches were located between every 4 beds. Standard pesticides and cultural practices were used (Hochmuth, 1988a). The monthly means after transplanting were 18.5 °C for Feb. and 21.2 °C for March.

Plants for root samples were shovel-excavated at times noted below at 20 x 20 cm (side x side) from the center of the plant and at the 30 cm depth. Plants were first gently shaken with a shovel, grasped by the stem, placed in polyethylene bags, and transported to 5 °C rooms, where they remained for 1 to 2 days until examined. Shoots were excised at the soil surface. Stem diameter was measured with a digital caliper just below the cotyledonary node. Stem length was measured from the shoot apex to the cut end, and leaf area (LA) was measured with a LI-COR (Model LI-3100) leaf area meter. Soil was washed from the roots, and roots collected from the medium using a 1-mm^2 screen. After root fresh weight was measured, plant material was oven-dried separately at 65 °C for 3 days and dry weights of leaves (LDW), stems, and roots were recorded. Shoot:root ratios (S:R), specific leaf area (SLA=LA/LDW), and relative growth rates (RGR) were calculated (Hunt, 1982). Fruits were harvested at the mature green stage from 10 plants per replication on 2 May, 17 May, and 6 June, 89, 104 and 124 days after transplanting, respectively. Fruits were graded

(USDA, 1976) into large (65-70 mm) and extra large (> 70 mm) sizes, counted, and weighed. Since the field environment was considered near-optimum for plant growth, medium (57-65 mm) fruits were left on the plants for further growth. Misshapen, diseased, or undersized (< 57 mm) fruits were considered culls.

A randomized complete block design with four replications was used for each treatment. Plants were sampled (2/replication) destructively at 0, 7, 14, 21, and 28 days after planting. Effects of transplant age were partitioned into linear or quadratic orthogonal responses. Data for leaf, stem, and root growth (dry wt.) were analyzed by polynomial regression (SAS Institute, Cary, N.C.). Fruit yield data were subjected to analysis of variance and orthogonal contrasts. Means were separated by LSD (0.05).

Experiment 2 Spring 1989. Transplants were set at a commercial farm in Bradenton, Florida on a sandy soil (sandy, siliceous, hyperthermic, Alfic Haplaquods) on 2 Feb. 1989. The transplants were 3 (3W), 4 (4W), 5 (5W) or 6 (6W) weeks old. Plants were grown on single raised (20 cm) beds covered with black polyethylene mulch. Plants were spaced 1.8 m between rows and 0.5 m within rows. Preplant fertilization (39N-100P-82K kg·ha^{-1}) and topdress fertilizer (216N-311K kg·ha^{-1}) were applied as for experiment 1. Drip tubing, Netafim (Altamonte Springs, FL), was positioned 15 cm deep and 25 cm to the side of the plants.

Drippers were spaced 60 cm apart with a drip discharge rate of 2.25 $l \cdot h^{-1}$. Water table was maintained 40 cm from the top of the bed. Fumigation was performed as for experiment 1. Plant sampling (2/plot) was initiated at transplanting and continued until 21 days thereafter (DAT). A late freeze in Feb. killed these plants, so no yields were obtained. Measurements and data analysis were as for experiment 1.

Experiment 3 Fall 1989 Transplants were set on 17 Aug. 1989 in Parrish, Florida, at the same field location as used for experiment 1. Transplant ages were 2 (2W), 3 (3W), 4 (4W) or 5 (5W) weeks old. Cultural practices were the same as described for this location, except that within-row plant spacing was 0.75 m and beds were mulched with white polyethylene mulch. Plant sampling (2/plot) was done at 0, 7, 14, and 21 DAT. The monthly means after transplanting were 28.6 °C for Aug. and 27.9 °C for Sep. Medium, large, and extra large fruits were harvested from 10 plants per replication on 31 Oct., 15 Nov., and 4 Dec. 1989, or 75, 90, and 109 days after transplanting. Growth measurements and data analysis were the same as described above.

Experiment 4 Fall 1989 Transplants were set on Aug. 17, 1989 in Bradenton, Florida, in the same field as used for experiment 2. Transplant ages were 2 (2W), 3 (3W), 4 (4W) or 5 (5W) weeks. All experimental and cultural practices were the same as described previously for this location. Monthly temperature means after transplanting were 28.3 °C

for Aug. and 27.7 °C for Sep. Chlorophyll (Chl) content was determined on the newest fully expanded leaflet (> of 2 cm length) (Arnon, 1949). Each sample was composed of six leaflets, each taken from different plants on each replication. Measurements were performed using a UV/VIS Lambda 3A spectrophotometer at 663, 652, and 645 nm, with Chl a, b, and a+b being determined in $mg \cdot g^{-1}$ fresh weight (FW) determined, and the Chl a/b ratio calculated. Samplings, growth measurements and data analysis were conducted as before.

Results

Experiment 1 Spring 1989. Stem length, leaf area, and root fresh weight increased linearly with increasing transplant age at 1 (T1) and 2 (T2) weeks after transplanting (Table 3-1). At T1 and T2, 5W and 6W transplants had greater leaf (Fig. 3-1A), stem (Fig. 3-1B), and root (Fig. 3-1C) dry weights than 3W or 4W transplants. However, at T3 dry weights were not significantly different between 4W, 5W, and 6W transplants. Initially, 3- and 4-week-old transplants had higher relative growth rates (RGR) than older transplants (Table 3-2). The low RGR values during the second week were probably due to low mean maximum/minimum (23/9 °C) temperatures.

Early and total (pooled harvests) fruit yield were similar among transplant age treatments (Table 3-3). Five

Table 3 1 Shoot and root characteristics of tomato transplants as affected by age Spring 1988 Expt 1 at Parrish Fla and Expt 2 at Bradenton, Fla

Transplant age[a]	Stem length (cm)			Stem diameter (mm)			Leaf area (cm^2)			Root fresh wt (mg)		
	T_0	T_1	T_2	T_0	T_1	T_2	T_0	T_1	T_2	T_0	T_1	T_2
Experiment 1												
3W	3 9	6 1	8 3	1 6	3 3	4 8	9	38	106	77	208	457
4W	6 0	7 3	9 4	2 3	4 4	5 0	21	63	110	178	407	633
5W	7 3	9 4	12 9	2 6	4 1	5 3	26	62	204	387	653	1318
6W	8 3	11 3	14 9	2 6	3 8	3 6	28	81	211	493	661	1366
Significance	Q*	L**	L**	Q**	Q*	L*	L**	L**	L**	L**	L**	L**
Experiment 2												
3W	3 5	5 8	7 3	1 6	3 2	4 3	9	33	64	77	139	377
4W	6 0	7 3	8 8	2 5	4 3	5 0	21	55	98	178	362	619
5W	7 3	9 2	10 9	2 6	3 8	4 5	26	61	123	387	427	793
6W	8 3	11 7	13 9	2 6	4 1	5 1	28	83	172	493	688	1237
Significance	Q*	L**	L**	Q**	Q*	L*	Q**	L**	L**	L**	L**	L**

[a]3W = 3 weeks 4W = 4 weeks, 5W = 5 weeks, 6W = 6 weeks T_0 = time at initial transplanting, T_1 and T_2 are times 1 and 2 weeks after transplanting

* **Significant F test at P = 0 05 or 0 01, respectively Transplant age effect was linear (L) or quadratic (Q)

Fig. 3-1. Leaf (A), stem (B), and root (C) growth (dry wt.) as affected by transplant age. Expt. 1, Farrieh, Florida, Spring 1989. Transplant age effects were linear (L), quadratic (Q), or cubic (C) at the time of transplanting (T0), 1 (T1), 2 (T2), 3 (T3), or 4 (T4) weeks after transplanting. Vertical bars represent ± SE.

A:T0 (Q, r^2 =90), T1(Q, r^2 =76), T2 (C, r^2 =87), T3 (Q, r^2 =84), T4 (Q, r^2=36)

B:T0 (L, r^2 =91), T1(Q, r^2 =91), T2 (L, r^2 =87), T3 (Q, r^2 =76), T4 (Q, r^2=56)

C:T0 (Q, r^2 =82), T1(L, r^2 =75), T2 (L, r^2 =78), T3 (Q, r^2 =70), T4 (Q, r^2=70)

A
B
C
LEAF WEIGHT (g)
STEM WEIGHT (g)
ROOT WEIGHT (g)
T4
T3
T2
T1
T0
TRANSPLANT AGE (weeks)

Table 3.2 Influence of tomato transplant age on mean relative growth rate (RGR) following transplanting, Spring 1988 Expt 1 at Parrish Fla and Expt. 2 at Bradenton Fla.

Transplant Age[1]	RGR ($g \cdot g^{-1} \cdot day^{-1}$)			
	T_0-T_1	T_1-T_2	T_2-T_3	T_3-T_4
		Experiment 1		
3W	0.112	0.069	0.089	0.034
4W	0.103	0.040	0.125	0.042
5W	0.067	0.067	0.094	0.040
6W	0.061	0.063	0.084	0.036
LSD (0.05)	0.026		0.032	--
		Experiment 2		
3W	0.105	0.054	0.098	
4W	0.086	0.040	0.099	-
5W	0.044	0.051	0.100	-
6W	0.066	0.049	0.081	
LSD (0.05)	0.020			

[1]3W = 3 weeks 4W = 4 weeks 5W = 5 weeks 6W = 6 weeks. T_0-T_1, T_1-T_2, T_2-T_3, and T_3-T_4 are weekly time intervals after transplanting.

Table 3-3 Effects of tomato transplant age on yields, fruit number and average fruit weight (Expt 1 Parrish, Fla Spring 1988)

Transplant age[1]	Early harvest[2]			All harvests		
	Large	Extra large	Total	Large	Extra large	Total
			Yield (t·ha^{-1})			
3W	14 3	14 0	28 2	60 7	32 0	92 7
4W	18 4	17 2	35 6	71 2	32 7	103 9
5W	20 4	21 2	41 5	63 7	39 2	102 9
6W	13 8	16 4	30 2	56 8	31 5	88 3
Significance	Q*	NS	Q*	Q*	NS	Q*
			Fruit number/plant			
3W	13 3	9 1	22 4	52 3	20 5	72 7
4W	17 3	10 9	28 2	62 1	20 5	82 7
5W	19 3	13 6	32 9	56 6	25 1	81 7
6W	13 0	10 6	23 6	48 7	20 1	68 8
Significance	Q*	NS	Q*	Q**	NS	Q*
			Average fruit weight (g)			
3W	134	192	157	146	196	160
4W	133	197	158	143	199	157
5W	132	194	157	140	195	157
6W	133	194	160	146	196	161
Significance	NS	NS	NS	NS	NS	NS

[1]3W = 3 weeks 4W = 4 weeks 5W = 5 weeks 6W = 6 weeks
[2]Harvests were at 89 (early), 104 and 124 days after transplanting. Fruit diameters were 65 70 mm (large) and > 70 mm (extra large).
NS, *, **Nonsignificant or significant F test at P = 0 05 or 0 01, respectively. Transplant age effect was linear (L) or quadratic (Q).

week-old transplants had 47 % more early large fruit yield and 48 % more fruit number than 6W transplants. Also, 4W transplants had more (25%) large fruit yield than 6W transplants.

Experiment 2 Spring 1989 Stem length, stem diameter, and root fresh weight at T0 increased with increasing transplant age from 3 to 6 weeks (Table 3-1). Leaf, stem, and root dry weight increased uniformly with increasing transplant age at T1 and T2. However, at T3, differences were not significant (Figs. 3-2A, 3-2B, 3-2C). Younger transplants (3W and 4W) had the greatest RGR values, though only during the first week of growth (Table 3-2).

Experiment 3 Fall 1989 Transplants of 4W and 5W plants had greater stem length than 2W and 3W plants (Table 3-4). At T0, leaf area increased uniformly with increasing transplant age from 2W to 5W; however, these differences were minimal at T1. Similarly, at T0, leaf weight increased linearly with increasing transplant age, but these differences were not observed thereafter (data not shown). Similar responses were measured for stem and root dry weight.

Early total and total marketable fruit yields were similar among treatments (Table 3-5), and trends did not depend on transplant age. Four-week old transplants produced greater early extra-large fruit and 64 % greater total extra large fruit yield than 5W transplants

Fig. 3-2. Leaf (A), stem (B), and root (C) growth (dry wt.) as affected by transplant age. Expt. 2, Bradenton, Florida, Spring 1989. See footnotes of Fig. 3-1 for other descriptions.

A: T0 (Q, r^2 =90), T1 (L, r^2 =83), T2 (L, r^2 =74), T3 (Q, r^2 =52)

B: T0 (L, r^2 =91), T1 (L, r^2 =88), T2 (L, r^2 =74), T3 (Q, r^2 =53)

C: T0 (Q, r^2 =82), T1 (L, r^2 =79), T2 (L, r^2 =78), T3 (Q, r^2 =59)

A
B
C
LEAF WEIGHT (g)
STEM WEIGHT (g)
ROOT WEIGHT (g)
3.0
1.5
0
0.8
0.6
0.4
0.2
0
0.4
0.3
0.2
0.1
0
T3
T2
T1
T0
3
4
5
6
TRANSPLANT AGE (weeks)

Table 3 4. Shoot characteristics of tomato transplants as affected by age, Fall 1983. Expt 3 at Parrish, Fla. and Expt 4 at Bradenton, Fla.

Transplant age[z]	Stem length (cm)			Stem diameter (mm)			Leaf area (cm^2)		
	T_0	T_1	T_2	T_0	T_1	T_2	T_0	T_1	T_2
Experiment 3									
2W	4.2	7.8	11.0	1.6	3.5	8.4	6	27	200
3W	5.5	8.1	11.2	2.1	3.2	8.5	10	40	203
4W	8.3	9.6	15.7	2.6	3.8	8.6	21	41	390
5W	13.1	11.5	15.6	2.9	3.7	7.4	30	30	195
Significance	Q**	L**	L**	L**	NS	NS	L**	Q*	NS
Experiment 4									
2W	4.2	6.9	11.3	1.6	2.8	4.3	6	20	122
3W	5.5	7.3	9.2	2.1	3.2	3.8	10	26	73
4W	8.3	9.5	12.9	2.6	3.7	4.6	21	38	114
5W	13.1	13.3	16.7	2.9	3.5	4.5	30	52	174
Significance	Q**	Q*	Q*	L**	L*	NS	L**	L**	NS

[z]2W = 2 weeks, 3W = 3 weeks, 4W = 4 weeks, 5W = 5 weeks. T_0 = time of initial transplanting. T_1 and T_2 are times 1 and 2 weeks after transplanting.

NS, *, **Nonsignificant or significant F test at P = 0.05 or 0.01, respectively. Transplant age effect was linear (L) or quadratic (Q).

Table 3.5 Effects of tomato transplant age on yields, fruit number, and average fruit weight (Expt 3, Parrish, Fla. Fall 1989)

Transplant age[1]	Early harvest[2]			Total harvests			
	Large	Extra large	Total	Medium	Large	Extra large	Total
				Yield (t·ha^{-1})			
2W	5.1	5.8	10.9	5.1	26.7	12.5	44.3
3W	7.7	5.3	13.0	7.9	30.4	10.5	48.9
4W	5.7	7.7	13.4	5.8	27.2	14.4	47.5
5W	6.1	2.9	8.9	6.1	28.1	8.8	42.4
Significance	NS	NS	NS	NS	NS	NS	NS
				Fruit number/plant			
2W	5.8	4.4	10.2	7.4	29.3	9.6	46.2
3W	8.6	4.2	12.9	11.3	33.8	8.7	53.8
4W	6.0	6.7	12.7	8.3	29.5	12.2	50.0
5W	7.0	2.3	9.4	8.6	31.2	6.5	46.3
Significance	NS	NS	NS	NS	NS	NS	NS
				Average fruit weight (g)			
2W	141	205	170	111	145	205	152
3W	143	197	161	112	143	193	144
4W	156	186	167	111	147	186	151
5W	136	195	150	111	143	204	145
Significance	NS	NS	L*	NS	NS	NS	NS

[1]2W = 2 weeks 3W = 3 weeks 4W = 4 weeks 5W = 5 weeks
[2]Harvests were at 75 (early), 90, and 109 days after transplanting. Fruit diameters were 57-65 mm (medium) 65-70 mm (large), and > 70 mm (extra large)
NS, *Nonsignificant or significant F-test at P = 0.05. Transplant age effect was linear (L)

Experiment 4 Fall 1989 Chlorophyll (Chl) a+b content ($mg \cdot g^{-1}$ FW) of the transplants increased through 4 weeks after transplanting (Fig. 3-3A). At T0, Chl a+b for 2W seedlings was 1.736 (se±0.082), 44 and 17 % greater than values for the 5W and 4W seedlings. At T1 and T2, older transplants had more Chl a+b than younger transplants. Later this difference became nonsignificant. The ratio of Chl a/b increased with time (Fig. 3-3B). At T0, 2W transplants had significantly higher Chl a/b than older transplants, a difference which was less evident at T1 and T2, and insignificant by T4.

Specific leaf area (SLA) changed in response to increasing transplant age. At transplanting SLA was 0.438(se±0.021), 0.331(±0.011), 0.274(±0.007), and 0.255(±0.007) $cm^2 \cdot mg$ for 2W, 3W, 4W, and 5W old transplants, respectively. SLA decreased by T1, and by T2 values were not significantly different, ranging from 0.173 to 0.187 cm^2 mg for 5W and 2W, respectively.

Five-week transplants had longer stem length than younger transplants (Table 3-4), though stem diameter and leaf area increase to increasing transplant age stopped after T1. Fruit yield, fruit size, and fruit number were similar among treatments for all harvests (data not shown). Yields ($t \cdot ha^{-1}$) ranged from 14.8 (2W) to 15.7 (4W) for medium fruit, 24.7 (2W) to 25.5 (5W) for large fruit, and 4.2 (2W) to 5.2 (5W) for the extra-large fruit size.

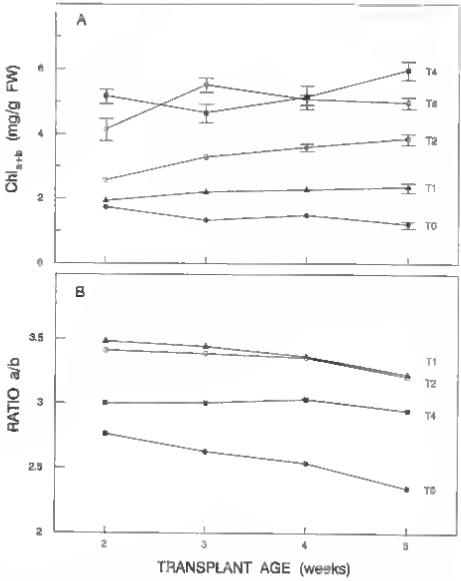


Fig. 3-3. Total Chlorophyll (Chl) a+b (A) and chlorophyll a/b ratio (B) as affactad by transplant aga at time of transplanting (T0), 1 (T1), 2 (T2), 4 (T4), or 6 (T6) weeks after transplanting.

Total yields accounted for 43.6 for 2W, 44.5 for 3W, 45.5 for 4W, and 46.8 for 5W old transplants.

Discussion

During seedling culture, it is probable that older transplants are exposed to more water and fertilizer stress than younger transplants. Widders (1989) and Dufault (1986) emphasized the importance of increasing the seedling nutrient content to enhance transplant growth after field setting. Nutrient deficiency and dehydration have been reported to decrease the permeability of roots, possibly due to suberization of cell walls (Passioura, 1988). For barley, root extension rate reductions and root thickening (Goss, 1977; Russell and Goss, 1974), was related to a decrease in cell length and to the length of the zone of cell extension (Goss and Russell, 1980). For 5W and 6W transplants, it was observed that the basal part of the root system eventually outgrows the container exposing roots to light and higher temperatures. These factors restrict continued root growth.

In the first experiment, 3W and 4W transplants had a greater capacity to resume growth than did 5W and 6W transplants (Table 3-2). The more rapid root and shoot growth rates for younger (3W and 4W) transplants were eventually translated into similar or higher large-fruit yields (Table 3-3). Weston and Zandstra (1989) reported

that early and total large-fruit yields for 3 to 6 week-old transplants grown under sprinkler irrigation were similar, though total yield increased linearly with increasing transplant age

In the second experiment most of the root and shoot parameters followed the same trend increases as in the first experiment, again indicating the growth advantages of younger transplants.

In the fall, the early differences in stem diameter and leaf area at T1 were not detected at T2 (Table 3-4). The dry weight results at T1 were difficult to relate to those at T2, since a considerable plant-to-plant variability occurred due to water flow reductions. The lack of differences in early and total marketable fruit yields indicated that no additional benefits were obtained with older transplants. Larger early-fruit yields were found for bareroot 5-week-old transplants as compared to 7- and 9-week-old transplants (Nicklow and Minges, 1962).

One reason for the significantly lower values of Chl a/b for older transplants at T0 may have been reduced light interception resulting from plant competition in the container. At T0, the leaf area index was 4.8 for 5W plants compared to 1.0 for 2W plants. For many plant species Chl a/b values of 2.5 to 2.9 have been reported for shaded leaves while and values of 3 to 3.5 are typical for sun-exposed leaves after planting (Czeczuga, 1987).

Therefore, the ratio of Chl a/b can be modified by growth conditions and environmental factors such as light (Lichtenthaler, 1987)

The high Chl a+b and Chl a/b values for younger transplants paralleled with higher specific leaf area at transplanting. The high SLA of young transplants indicated that their leaves, still in the process of extension, were thinner as compared with the thicker leaves of older transplants. It is suggested that younger transplants, with initially higher Chl a+b values, Chl a/b ratios, SLA values, and RGR had a more efficient photosynthetic system than older transplants.

Though the experiments were not designed to compare yields between seasons, values were higher in spring than in fall. In spring, the monthly means after transplanting were 18.5 °C for Feb. and 21.2 °C for March, whereas fall values were 28.6 °C for Aug. and 27.9 °C for Sep. Calvert (1959) reported that tomato plants grown at 15 °C flowered up to 13 days earlier than those grown at 25 °C, and Kemp (1968) indicated that any increase in the number of flowers after seedlings are exposed to low temperatures is a varietal response.

The initial favorable transplant growth characteristics acquired while growing in the greenhouse, most evident for older transplants, were modified in the field either under seepage or drip irrigation. Transplants which were 4 weeks

old in fall and 5 weeks old in spring had similar or higher yields than older transplants. Therefore, no improvement in fruit yields is to be expected using the traditional older 5W and 6W plants instead of younger transplants. Use of younger transplants offers the dual advantages of rapid seedling establishment and minimal transplant production costs.

Summary

Studies were conducted to evaluate growth of tomato (Lycopersicon esculentum Mill.) transplants in the field in response to transplant age during spring and fall 1989. Transplants were 2 (2W), 3 (3W), 4 (4W), 5 (5W) and 6 (6W) weeks of age. Drip and seepage irrigation were used. In the spring, older transplants produced more shoot and root growth up to 2 (T2) weeks after transplanting. At 3 (T3) and 4 (T4) weeks after transplanting, growth was similar among 4W, 5W, and 6W transplants. These trends were independent of irrigation system. Total yield and early yield were not different between transplant age treatments. In the fall, shoot growth increased linearly with increasing transplant age at T0 (the transplanting date), but not thereafter. Chl a+b increased over time, but no treatment differences were found at T4. At planting, 2W transplants had a higher chl a/b ratio than older transplants. This difference was reduced by T1 and T2, and became

insignificant by T4. Total fruit yields were unaffected by transplant age. These results indicate that no improvement in yields was obtained using the traditional older transplants.

CHAPTER 4

TOMATO TRANSPLANT GROWTH MORPHOLOGY AS AFFECTED BY HANDLING AND STORAGE

Introduction

Containerized transplants are used extensively in tomato production regions (Rlese et al. 1979; Weston and Zandstra, 1986). In Florida, transplants are generally shipped directly to growers in the trays used for transplant production. Field establishment occurs one to three days after plant arrival. Transplants shipped out of Florida are hand-pulled from the trays, packed at high densities in waxed-cardboard boxes, and transported at approximately 14 °C in closed containers. Using this system, transplants can be transported at low costs. Field establishment may be delayed from one to seven days, depending on weather conditions at planting site and distance to market.

Transplant age at shipping depends on grower's preference. Growers in the northern U.S. prefer tomato transplants that are at least six-weeks old and tall (12 to 15 cm). Growers in Florida prefer transplants that are five-week old and short (10 cm) (R. Bostdorff, Speedling Inc. personal communication).

The negative influence of extreme-temperature holding conditions for bareroot transplants was reported for some crops. For potato transplants, tuber and stolon development continued when plants were stored above 7.2 °C for 4 to 8 days (Risse et al., 1984). For celery transplants, tissue deteriorated when stored above 10 °C (Jardine et al., 1984). Survivability decreased for sweet potato transplants stored for 7 days at either 4.4 or 26.7 °C (Hammatt, 1985).

For tomato, studies on shipping containers, storage time, and temperature have been reported for bareroot transplants (Risse and Moffit, 1984) and for transplants grown in Speedling trays (Risse et al, 1979). Storage temperature between 10 and 13 °C for less than 10 days is generally recommended for tomato plants (Hardenburg et al., 1986). Plant survival and fruit-yield reduction was reported for bareroot transplants packed at 1250 plants/crate (Risse et al., 1985).

Transplant studies have not considered growth changes during storage. Knowledge of such growth changes should be useful to optimize transplant handling and storage prior to field establishment.

This study was conducted to determine the effects of transplant handling (a) on shoot and root growth changes during extended low-temperature storage, and (b) on early growth and fruit yield after reduced ambient-temperature storage.

Materials and Methods

Experiment 1 'Sunny' tomato plants were grown for 45 days at Speedling Inc., Bushnell, FL. Speedling® polystyrene trays with 200 inverted pyramid cells of 2.5 cm x 7.2 cm (side length x depth) and 18 cm^3 were used for growing the seedlings. Greenhouse transplant-production practices were standard propriatary procedures of Speedling Inc., Bushnell, Florida (Beirsinger and Bostdorff, 1989). Handling treatments were (a) transplants that were kept directly in trays (Not Pulled) and then packed in wax-cardboard boxes and (b) transplants that were hand-pulled (Pulled) from trays and packed upright in wax-cardboard boxes, at a density of 850 plants per box of 22 x 45 x 52 cm (height x width x length). Not Pulled and Pulled transplants were kept in cold rooms at 5 and 15 °C for 0, 2, 4, 6, and 8 days, in darkness. Air temperature at the leaf and root-media level were recorded hourly using a Grant Squirrel meter/logger (Science Electronics, Dayton, Ohio 45401) with 16 thermistor probes placed on the Pulled and Not Pulled transplant boxes, at both 5 and 15 °C cold rooms. Stem diameter was measured with a digital caliber below the cotyledonary node. Stem length was measured from the shoot apex down to the cut end and leaf area was measured with a LI-3100 leaf area meter (LI-COR, Lincoln, Nebraska 68504). After roots were washed they were blotted and root fresh weight was determined. Plant material was oven dried at

65 °C for 3 days and dry weights of leaves, stem, and roots were recorded. Shoot:root ratios and specific leaf area (leaf area/leaf dry weight) were calculated. Measurements were made prior to (0 day) and after 2, 4, 6, and 8 days of storage.

A randomized complete block design with 10 replications (1 plant/rep) per handling treatment was used at each storage time. Data for each storage temperature were analyzed separately by ANOVA. The main effect of storage time was partitioned into linear, quadratic, or cubic orthogonal contrasts.

After 8 days of storage, ethylene evolution was determined for transplants from each handling treatment and storage temperature. Individual transplants were cut at the hypocotyl base, weighed, placed in a 35-ml test tube, sealed with a serum cap, and kept in the light at 23 °C. A randomized complete block design with 4 replications per handling treatment was used. Samples (1/rep) were withdrawn hourly over a 5-hour period. Ethylene was measured with a gas chromatograph using a flame-ionization detector and an activated alumina column.

Experiment 2 'Sunny' tomato plants were grown for 35 days in polystyrene trays with 150 inverted pyramid cells of 3.8 cm x 6.4 cm (side length x depth) and 30.7 cm^3 volume. Treatments were the same as in experiment 1, (Not Pulled and Pulled), with the exception that Pulled transplants were

packed at a density of 550 plants/box. At 35 days after seeding, plants from each transplant group were kept in a closed container at 20/28 °C (night/day), for 0, 1, 2, and 3 days. Just prior to transplanting stem diameter, stem length, leaf area, dry weight of leaves, stems, and roots, specific leaf area and shoot:root ratios were measured and calculated similarly as for experiment 1.

Transplants were established in the field on 17 Aug. 1989 at Bradenton, Florida on a sandy soil (sandy, siliceous, hyperthermic, Alfic Haplaquods). Raised beds, 0.2 m in height; were spaced 1.8 m apart with each bed 0.8 m wide. Preplant fertilization (39N-100P-62K kg·ha^{-1}) was applied broadcast and incorporated into the bed. Topdress fertilizer (216N-311K kg·ha^{-1}) was applied in two bands on the bed surfaces, 25 cm to each side of the bed center. Beds were fumigated with methylbromide-chloropicrin (2:1) at 207 kg·ha^{-1} and covered with white polyethylene mulch (0.038-mm). Plants were spaced at 0.50 m intervals within the bed. Plants were staked (1 stake every 0.6 m) and then were tied four times. Drip tubing, Netafim, was positioned 15 cm depth and 25 cm laterally. Drippers were spaced at 60 cm apart with a drip discharge rate of 2.25 l·h^{-1}. Daily irrigation maintained the water table at 40 cm from the top of the bed. Fruits were harvested at the mature-green stage from 10 plants on 31 Oct., 15 Nov., and 4 Dec. 1989, 75, 93

and 115 days after transplanting. Fruits were graded by size (USDA, 1976) into medium, large, and extra large, counted and weighed.

A randomized complete block design with treatments replicated four times were used. Analysis of variance was performed for each measured and calculated variable. Treatment effects were partitioned into orthogonal contrasts.

Results and Discussion

Experiment 1 At 5 °C, Pulled transplants had 10 % longer stem length, 11 % more stem dry weight, 14 % more specific leaf area, 16 % higher shoot:root ratio, and smaller root fresh and dry weight than Not Pulled transplants (Table 4-1). Shoot growth promotion for Pulled transplants was possibly a response to higher air temperatures in the shoot and root environment than for Not Pulled transplants (Fig. 4-1), due to respiration heat generated by the high packing density (Riess et al., 1965). Conversely, the root growth limitation in Pulled transplants could have been due to an excess moisture in the root environment, reducing oxygen diffusion rates (Miller, 1986).

Storage time main effect was quadratic for stem diameter, with a rapid increase from 0 to 2 days followed by a levelling off thereafter. After eight days of storage the proportion of leaf dry weight (% basis) decreased from 53 to

Table 4.1 Means for root and shoot components in response to tomato transplant handling and storage time at 5°C (Expt 1)

Source of variation	Stem diameter (mm)	Stem length (cm)	Leaf area (cm^2)	Root fresh wt (mg)	Dry weights Leaf (mg)	Stem (mg)	Root (mg)	Specific leaf area ($cm^2 \cdot g^{-1}$)	Shoot root ratio
Handling method (HM)									
Not Pulled	2.4	13.2	33.8	418	160	110	46	0.214	6.1
Pulled	2.5	14.6	38.9	384	163	122	42	0.243	7.1
Significance	NS	**	**	*	NS	**	*	**	**
Storage time (days)									
0	2.0	13.1	35.8	396	169	108	43	0.213	6.7
2	2.6	14.0	35.0	390	163	117	42	0.219	6.8
4	2.7	14.4	37.6	426	170	121	47	0.225	6.4
6	2.5	14.2	36.4	395	156	113	45	0.238	6.4
8	2.6	13.6	36.9	398	149	116	42	0.250	6.6
Significance	Q**	NS	NS	NS	NS	NS	NS	L**	NS
Interaction									
HM x Time	NS	NS	*	NS	NS	NS	NS	NS	NS

NS, *, **Nonsignificant or significant F test at P = 0.05 or 0.01, respectively. Significant time effects were linear (L) or quadratic (Q)

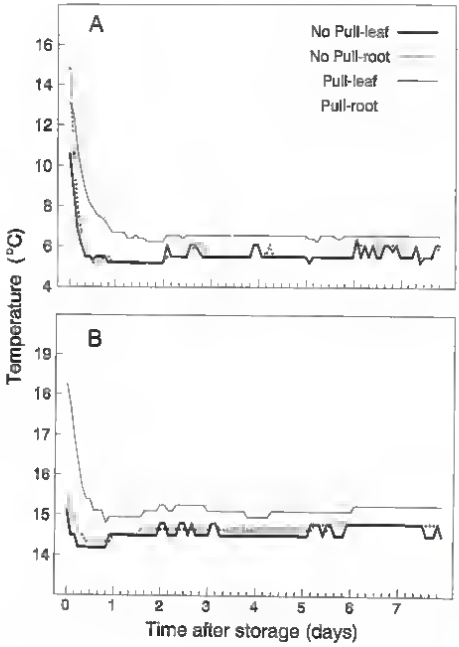


Fig. 4-1. Average air temperature at the leaf and root level for Not Pulled and Pulled transplants maintained at (A) 5 C and (B) 15 C.

49 %, stem weight increased from 34 to 38 %, and root dry weight remained at 13 % (Table 4-1).

Specific leaf area increased linearly as storage time increased, indicating that growth was maintained primarily at the expense of leaves which were becoming thinner. The high shoot:root ratio for Pulled transplants was due to greater shoot and lower root growth as compared with Not Pulled transplants.

The handling method x storage time interaction for leaf area (LA) was partitioned for each storage time (Fig. 4-2). LA for Pulled transplants increased for up to four days, at which time LA was 35 % larger than for Not Pulled transplants which maintained the same initial LA value over time. Pulled transplants were packed at higher density (3,730 plants·m^{-2}) than Not Pulled transplants (880 plants·m^{-2}). Pulled transplants cooled more slowly and plants were maintained about 1.5 °C higher than Not Pulled plants. Lower cooling rates for bareroot transplants packed 2400 plants/box compared to 1450 plants/box were reported (Risse and Moffit, 1984).

Temperatures between 10 and 15 °C have been reported to suppress root growth for bareroot tomato transplants (Moren et al., 1962; Hardenburg et al., 1986). Data from the present experiment indicate that shoot and root growth continued even at lower temperatures.

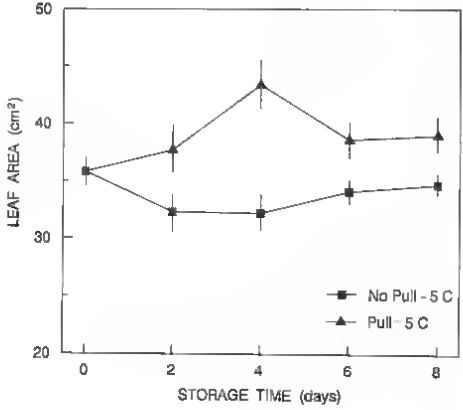


Fig. 4-2. Effects of storage time on leaf area for Not Pulled and Pulled transplants stored at 5 C.

At 15 °C, Pulled transplants had 10 % longer stem length, more leaf area and stem dry weight, and 14 % more specific leaf area (SLA) than Not Pulled transplants (Table 4-2). Leaf and stem growth increased from 0 to 4 days, with a decrease thereafter. SLA evidenced a quadratic increase with an exponential increase after 6 days, at which time lower leaves began to turn yellow and leaf deterioration was accentuated after 8 days of storage. At the end of the storage period leaf dry weight (% basis) decreased from 53 to 43%, stem weight increased from 34 to 42% and root weight increased from 13 to 15%.

The significant handling method x storage time interaction for root dry weight (RDW) was partitioned for each storage time (Fig. 4-3). Not Pulled transplants had a uniform RDW increase up to 4 days and then, decreased thereafter. Root growth for Pulled transplants evidenced a two-day delay, then growth continued up to 6 days, and declined thereafter. The initial root growth delay may have resulted from the combined effect of pulling and packing compaction and high moisture levels. After 6 days, transplant separation was difficult due to root binding. Root deterioration was compensated with new growth from basal and lateral roots, a response which had been previously reported for bareroot transplants stored at 10 to 15 °C for 10 days (Jaworski et al., 1967).

Table 4-2 Means for root and shoot components in response to tomato transplant handling and storage time at 15°C (Expt 1)

Source of variation	Stem diameter (mm)	Stem length (cm)	Leaf area (cm^2)	Root fresh wt (mg)	Dry weights Leaf (mg)	Dry weights Stem (mg)	Dry weights Root (mg)	Specific leaf area ($cm^2 \cdot g^{-1}$)	Shoot root ratio
Handling method (HM)									
Not Pulled	2 5	13 4	34 5	433	156	115	47	0 227	5 7
Pulled	2 6	14 8	39 4	435	163	127	47	0 250	6 3
Significance	NS	**	**	NS	NS	*	NS	**	NS
Storage time (days)									
0	2 0	13 1	35 8	396	169	108	43	0 213	6 7
2	2 7	14 8	34 8	384	158	119	43	0 209	6 8
4	2 9	14 2	40 6	492	182	136	55	0 232	5 8
6	2 8	14 2	36 7	450	148	118	50	0 250	5 5
8	2 4	14 3	37 0	447	131	125	44	0 268	5 8
Significance	Q**	NS	NS	L**	Q*	Q*	Q**	Q**	C*
				Interaction					
HM x Time	NS	NS	NS	NS	NS	NS	**	NS	NS

NS = *, **Nonsignificant or significant F test at P = 0 05 or 0 01, respectively. Significant time effects were linear (L), quadratic (Q), or cubic (C)

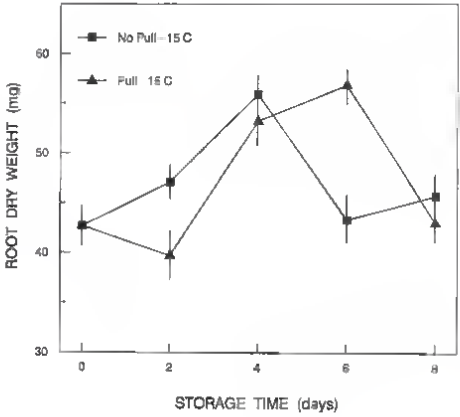


Fig. 4-3. Effects of storage time on root dry weight for Not Pulled and Pulled transplants stored at 15 C.

Pulled transplants had significantly higher ethylene evolution than Not Pulled transplants. At 5 °C ethylene was also higher than at 15 °C (Table 4-3). The significant handling x temperature interaction showed that ethylene evolution ($mg \cdot g^{-1} \cdot hr^{-1}$) for Not Pulled transplants was 2.5 (SE±0.3) at 5 °C and 2.2 (±0.2) at 15 °C, and for Pulled transplants corresponding values were 5.3 (±0.3) at 5 °C and 2.1 (±0.2) at 15 °C.

Ethylene stimulation for Pulled transplants kept at 5 °C was probably due to the additive stresses of excess moisture, chilling temperature, and physical stress (Abeles, 1973). In tomato seedlings, anaerobic environment in the root zone due to waterlogging increases ethylene synthesis in the shoot (Bradford and Dilley, 1978), by exporting the immediate ethylene precursor 1-aminocyciopropane-1 carboxylic acid (ACC) via the transpiration stream from the low-oxygen roots to the shoots (Bradford et al., 1982). Under these conditions, ethylene has been suggested to exert a control on root growth extension (Jackson, 1985). In this experiment Pulled transplants had lower root growth (both fresh and dry wt. basis) than Not Pulled transplants kept at 5 °C (Table 4-1). After 4 days at 15 °C, basal roots and newly formed lateral root growth proliferation were observed (Fig. 4-3). This response may have in turn given access to oxygen, thereby reducing ethylene evolution.

Table 4-3 Ethylene evolution for Not Pulled and Pulled tomato transplants after 2 days of storage at 5 and 15°C (Expt 1)

Source of variation	Ethylene ($nl \cdot g^{-1} \cdot hr^{-1}$)
Handling method (HM)	
Not Pulled	2.3
Pulled	3.7
Significance	**
Storage temperature (°C)	
5	3.9
15	2.2
Significance	**
	Interaction
HM x Temperature	**

**Significant F test at P = 0.01

Experiment 2 Pulled transplants were packed at a density of 2,350 plants·m^2, while Not Pulled transplants were packed at 658 plants·m^2. Not Pulled transplants had significantly larger stem length, leaf area, and stem and root dry weight than Pulled transplants (Table 4-4). The shoot and root growth decrease for Pulled plants could have been due to the interaction of high air temperature, darkness, and the physical effects of pulling and packing. Stem and leaf dry weight decreased as storage time increased from 0 to 2 days both for Not Pulled and Pulled transplants. Conversely, SLA increased as storage time increased (Table 4-4). High SLA values are typical for leaves under shade (Jones, 1982).

Partitioning of the significant handling method x time interaction for each storage time indicated that, at 2 days after storage, Pulled transplants had higher SLA, lower root dry weight, and higher S:R ratio than Not Pulled transplants.

Plant survival was 100% and therefore not affected by transplant handling or storage time. Reduced plant survival has been reported for field-grown transplants packed at a high density, 1250 plants/crate (Risse et al., 1985), and for containerized transplants stored for 10 or 15 days (Risse et al., 1979).

At the first harvest, Not Pulled transplants had 68% more extra-large fruits than Pulled transplants (Table 4-5). At the second harvest, Not Pulled transplants had

Table 4 4. Shoot and root characteristics of tomato transplants as affected by transplant handling and storage time at 20/28°C (Expt 2)

Source of variation	Shoot: Stem length (cm)	Stem diameter (mm)	Leaf area (cm^2)	Shoot wt. (mg): Stem	Shoot wt. (mg): Leaf	Specific leaf area ($cm^2 \cdot g^{-1}$)	Root wt. (mg)	Shoot root ratio
Handling Method (HM)								
Not Pulled	8 3	3 2	30	76	120	242	48	4 1
Pulled	7 7	3 1	26	68	111	237	45	4 0
Significance	**	NS	**	*	NS	NS	*	NS
Storage time (days)								
0	8 6	3 2	28	83	133	212	49	4 4
1	8 1	3 2	28	79	130	216	54	3 9
2	7 4	3 0	27	59	97	266	40	4 0
3	7 7	3 1	28	66	102	265	44	3 9
Significance	C*	L**	NS	C**	C**	L**	C**	L**
				Interaction				
HM x Time	NS	NS	NS	NS	NS	**	**	**

NS, *, **Nonsignificant or significant F test at P = 0 05 or 0 01, respectively
Significant time effect were linear (L) or cubic (C)

Table 4-5 Effects of tomato transplant handling and storage time (20/28°C) on yields (Expt 2)

	Fruit yield (t·ha^{-1})							
	Early[a]			Mid			Late	
Source of variation	Medium	Large	Extra large	Medium	Large	Extra large	Medium	Large
Handling method (HM)								
Not Pulled	3 3	10 3	3 7	4 8	14 6	3 2	8 6	10 1
Pulled	4 1	9 2	2 2	3 1	17 8	1 9	7 9	9 4
Significance	NS	NS	**	**	*	*	NS	NS
Storage time (days)								
0	3 7	10 4	3 5	4 6	16 7	2 5	8 7	9 3
1	2 8	10 3	3 4	4 0	17 9	2 2	7 9	9 9
2	3 5	9 0	2 6	4 4	16 9	2 7	8 4	8 2
3	4 7	9 3	2 4	2 9	13 4	3 0	8 3	11 4
Significance	NS	NS	L*	NS	NS	NS	NS	NS

[a]Harvests were at 75 (early), 93 (mid) and 115 (late) days after transplanting. Fruit diameters were 57-65 mm (medium), 65-70 (large), and > 70 mm (extra large).

NS, *, **Nonsignificant or significant F test at P = 0.05 or 0.01 respectively. Significant time effect was linear (L). HM x storage time interaction was not significant.

significantly more medium (55%) and extra-large (68%), and less large (18%) fruits than Pulled transplants. There were no interactions between handling methods and storage time. Similarly, pooled across all harvests, Not Pulled plants had 71% more total extra-large fruits and more extra-large fruit numbers/plant than Pulled transplants (Table 4-6). Extra-large fruits accounted for 12% and 7% of the total marketable fruits for Not Pulled and Pulled treatments, respectively. However, total marketable fruit yield was not affected by storage time and there were no handling method x storage time interactions. Therefore, fruit sizing after transplanting was affected by pulling and packing. Significant fruit yield decrease has been reported (Risse et al., 1985) for bareroot transplants packed at 1250 plants/crate compared to the conventional 1000 plants/crate. Increased transplant storage time (to 3 days) before transplanting generally did not decrease fruit yield, with the exception of extra-large sized fruit in the first harvest (Table 4-5). It has been reported that, after 5 days of storage, yield of tomato transplants decreased with length of storage (Risse et al., 1979).

Results of the present experiments indicate that transplant maturity and handling affected transplant growth after 4 days of storage at either 5 or 15 °C. Not Pulled transplants which were 45 days old maintained better shoot and root characteristics compared to Pulled transplants.

Table 4-6 Effects of tomato transplant handling and storage time (20/25°C) on fruit size yield and fruit number (Expt 2).

	Fruit size[a]							
	Medium		Large		Extra large		Total	
Source of variation	Yield (t·ha^{-1})	No / plant	Yield (t·ha^{-1})	No / plant	Yield (t·ha^{-1})	No / plant	Yield (t·ha^{-1})	No / plant
Handling method (HM)								
Not Pulled	16 7	12 8	35 0	21 5	7 0	3 1	58 7	37 5
Pulled	15 1	11 7	36 4	22 9	4 1	1 8	55 6	36 4
Significance	NS	NS	NS	NS	**	**	NS	NS

[a]Fruit diameters were 57-65 mm (medium), 65-70 (large), and > 70 mm (extra-large). Fruit size and total yield were pooled across all harvests.
NS, **Nonsignificant or significant F-test at P = 0 01

Transplant storage temperatures should be selected to avoid the possibility of chilling injury and physiological disorders expressed in the plant after transplanting (Dufault and Melton, 1990) or fruit disorders, such as cutfacing, present in transplants conditioned at 10 to 18 °C prior to transplanting (Wien, 1990). Growth and fruit yield from transplants which were 35 days old were even more affected by transplant handling. Considerations should be given to minimize the effects of pulling and packing young transplants. If planting is delayed beyond two days, storage at lower (8 °C) than ambient temperatures would be desirable.

Summary

Shoot and root growth of tomato (Lycopersicon esculentum Mill.) transplants in response to handling and storage time was investigated. In expt. 1, 45-day old transplants were stored either in trays (Not Pulled) or packed in boxes (Pulled) for 0, 2, 4, 6, and 8 days at 5 and 15 °C. In expt. 2, 35-day-old Not Pulled and Pulled transplants were kept in darkness at 20/28 °C for 0, 1, 2, and 3 days.

At 5 °C, Pulled transplants had longer stem length, more stem weight, more specific leaf area (SLA), higher shoot:root ratio, higher ethylene evolution, and lower root

dry weight than Not Pulled transplants. At 15 °C, Pulled transplants had larger measured shoot-growth parameters than Not Pulled transplants.

In expt. 2, Not Pulled transplants had greater shoot and root weight than Pulled transplants. In both handling treatments, growth decreased as storage time increased. Not Pulled plants had significantly greater (7.0 $t.ha^{-1}$) extra-large fruit yields than Pulled transplants (4.1 $t.ha^{-1}$), but total marketable fruits were unaffected. These results indicate that transplant handling can affect subsequent growth during and after storage, leading to a reduction in the more valuable extra-large fruit.

CHAPTER 5

PEPPER SEEDLING GROWTH IN RESPONSE TO ABSCISIC ACID AND WATER STRESS

Introduction

The use of containerized pepper (Capsicum annuum L.) transplants is becoming an important production practice to improve stand uniformity and yields (Hochmuth, 1988b; Cantliffe, 1990). Such transplants are grown commercially in greenhouses for 5 to 8 weeks (Weston, 1988). During this period, environmental, physical, chemical, and genetic factors affect seedling growth and development.

A sub-flotation recirculating irrigation system has been developed for growing transplants in Florida. Water and nutrients entering the seedling tray cells move up through the substrate by capillarity. Under high irrigation frequency, it was observed that roots grew through the bottom of the cell. This response lead to the need for either mechanical or heated-blown-air root pruning, disrupting the root tip zone which was considered to be important for axial root growth (Filet and Saugy, 1987). A reduction of soil moisture will decrease root growth

(Schulze, 1986), with the extent of the decrease depending on the duration of the stress imposed on the seedlings.

Abscisic acid (ABA), which is synthesized in the root cap (Rivier et al., 1977) and root tip (Creelman et al., 1990) is generally involved in plant regulatory processes (Addicot, 1983). This is particularly true for water-stressed plants (Davis et al., 1981; Watts et al., 1981). The influence of water stress on root and shoot growth was suggested to be mediated through endogenous changes of ABA acting as a signal for control of growth processes (Davis et al., 1986). Water-stress-induced ABA has been correlated with a reduction of shoot/root ratio, either by shoot growth reduction (Creelman et al., 1990) or by a greater root growth relative to shoot growth (Karmoker and Van Steveninck, 1979). Investigations reporting the effects of ABA on conditioning of vegetable plants to withstand outdoor stress is minimal (Latimer and Mitchell, 1988).

This study was conducted to evaluate the effects of exogenous ABA and water stress on pepper seedling morphology and dry matter partitioning.

Materials and Methods

Germination and Seedling Tests

Preliminary experiments were conducted to determine the inhibitory effects of a range of exogenous ABA

concentrations on 'Jupiter' bell pepper seed germination and seedling growth.

Seeds were placed on Whatman No. 1 and No.3 filter papers in 9-cm Petri dishes and germinated in an incubator under dark conditions at 25 ± 1 °C. ABA(+/- cis, trans) (Sigma Chemical Co., St. Louis, MI) concentrations of 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} and 10^{-8} M were prepared and 5 ml of solution was added to the filter paper initially, followed by daily additions of 1 ml. A randomized complete block design (RCBD) was used. All treatments consisted of 4 replications of 50 seeds each. Germination was counted daily and total and mean days of germination (Gerson and Honma, 1978) calculated. Germination percentage was transformed to arc sins before being subjected to analysis of variance (ANOVA).

A rolled towel germination test was performed similar to that of the Association of Official Seed Analysts (AOSA, 1983). Three non-toxic germination papers (Anchor paper Co., St. Paul, MN) were soaked for 30 min in ABA solutions, then fifty seeds were placed in two rows and paper towels were rolled, placed in plastic containers (21.5 x 32.5 x 5.5 cm) and incubated in a dark germinator at 25 ± 1 °C for 7 days. Seedlings were classified as normal (with complete morphological parts), abnormal (with broken cotyledons, or

less then one cotyledon, missing primary root, poorly developed or absence of hypocotyl), and dead.

A RCBD was used, with each treatment being replicated four times. Percentage of normal, abnormal and dead seedlings were transformed to arc sine before being subjected to ANOVA. Root length of the primary root from 10 normal seedlings was measured and seedling vigor estimated by averaging dry weight of normal seedlings (AOSA, 1983).

Seedlings were grown in Speedling polyesterene trays with 200 cells 2.5 x 7.0 cm (side length x depth; 18 cm^3). Seeds were sown on 10 Nov. on a commercial mix (Terre-Lite Metro Mix 200) and covered with 1.25 ml of Vermiculite (Terre-Lite grade 2-3-4). Trays were transferred to germination chambers at 25 °C and 98 % RH for 4 days and then to a glass greenhouse with minimum/maximum temperature of 10/29 °C. Each cell was thinned to one seedling 17 days after seeding (DAS). Irrigation was applied three times/week with a nutrient solution (20-10-20) at 50 $mg \cdot l^{-1}$ of N, 12 $mg \cdot l^{-1}$ of P and 40 $mg \cdot l^{-1}$ of K. After 30 DAS the original concentration was doubled. ABA at 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} and 10^{-8} M plus 0.1 % v/v Tween 20 was sprayed on the upper leaves, until runoff, at 33 and 37 DAS.

After 60 DAS 2 plants/rep were removed from the trays with forceps and shoots were dissected at the soil surface. Stem diameter was measured with a digital caliber below the cotyledonary node. Stem length was measured from the shoot

apex down to the cut end and leaf area was measured with a LI-3100 leaf area meter (LI-COR). Roots were washed, blotted and root fresh weight determined. Plant material was oven-dried at 65 °C for 3 days and dry weights of leaves, stem, and roots were recorded. A RCBD with 4 replications of each ABA concentration was used. Data were subjected to ANOVA. The main effect of ABA concentration was partitioned into linear, quadratic, or cubic orthogonal contrasts.

Growth Chamber Experiment

Polyesterene trays with inverted pyramid cells of 2.5 x 7.2 cm (side length x depth; 18 cm^3) were cut into mini trays of 40 cells each. Each tray was considered an experimental unit. Mini trays were filled with 180 grams of Terra-Lite Metro Mix 200 with a water holding capacity 4.8 times greater than its own weight. Before germination, seeds were soaked in 1 % NaOCl for 10 min, rinsed with distilled water for 10 min, sown in each cell and covered with 1.25 ml of Vermiculite. Trays were irrigated with distilled water to 50% of the water-holding capacity of the mix and placed into a germination chamber in darkness at 25 °C, 98 % RH for 4 days. Trays were then placed in a 4-section plastic container so that an independent bottom watering and drainage system could be utilized. The trays were transferred to a 1.27 m^2-growth chamber (CONVIRON CMP 3023, Conviron Products Co., Winnipeg, Manitoba, Canada)

maintained at 60 % RH and day/night temperatures of 27/20 °C. Photoperiod was 14 hours, given with a combination of cool white fluorescent and incandescent lamps (SYLVANIA F72217/CW/VHO 160 W/ SYLVANIA 52 W, 4:1 input wattage ratio). The initial photosynthetic flux (LICOR LI-185 A, Lincoln, Nebraska) measured in 12 locations at 30 cm from the growth chamber floor averaged 326 $\mu mol \cdot s^{-1} \cdot m^{-2}$.

Seedlings were watered daily with distilled water to 50 % water holding capacity at 1400 HR until 22 DAS. Plants were thinned to one seedling per cell 13 DAS. Fertilization (20-10-20) was initiated 10 DAS at 50 $mg \cdot l^{-1}$ of N and after 30 DAS, the concentration was increased 2-fold. Solution pH was adjusted to 6.2 with 0.1M NaOH. At 23 DAS, plants in each block were randomly divided into four groups, two that received continuous daily watering (CW) and the other two that received alternate-day watering (AW). For the AW-treated seedlings, water was withheld until plants had symptoms of water stress (passive leaf flagging) occurring below approximately 20 % of water holding capacity, with seedlings then being re-watered (24, 26, 28, 30, 32, 34, 37, 39, 43, 45 and 48 DAS). ABA solution at 10^{-4} M plus 0.1 % v/v Tween 20 as a spreader was prepared. One of the two experimental plots of both the continuous and alternate-day watering plants were sprayed at 28, 32 and 37 DAS with ABA solutions on the upper leaf surfaces until runoff. Other plots were sprayed only with water and the spreader.

Stem diameter, stem length, leaf area, and dry weights of leaves, stems, and roots were determined as previously described, with measurements at 22, 26, 30, 35, 41 and 48 DAS. Shoot:root ratio was calculated for each plot. Relative growth rate and net assimilation rate were calculated from the original data set (Hunt, 1982). At 48 days after seeding basal and lateral roots were counted. Root diameter of basals, 1st order basals (originating from basals), laterals, and 1st order laterals (originating from laterals) were measured with a ORC stereo-microscope (Zeiss, Oberkochen, West Germany).

Seedlings grown in the growth chamber were set in a field located in Naples, Fla. (sandy, siliceous, hyperthermic, Alfic Arenic) on 29 Dec. 1988. Raised beds, 0.15 m in height, were spaced 1.8 m apart with each bed 0.8 m wide. Plants on single rows were spaced at 0.30 m within the bed. Fertilizer (36N-202P-72K kg·ha^{-1}) was broadcast and incorporated in the center of the bed. Topdress fertilizer (235N-423K kg·ha^{-1}) was applied in two bands in shallow grooves on the bed surface 20 cm to each side of the bed center. Beds were fumigated with methyl bromide:chloropicrin (67:33) at 392 kg·ha^{-1} and covered with black polyethylene mulch. Water table was maintained at 30 cm depth with seepage irrigation. Seepage irrigation ditches were located between every six beds. Standard pesticides and cultural practices were used (Hochmuth,

1988b). Fruits were harvested from 18 plants per replication on 22 March, 11 and 25 April 1989, counted and graded by size into fancy and U.S. No. 1 (USDA, 1963).

A RCBD with four replications was used at each harvest time. Since variance heterogeneity was measured for leaf and root dry weights over time, data were subjected to a log(X+1) transformation prior to ANOVA. Transformed means were separated by LSD (P=0.05). Main effects were partitioned into orthogonal contrasts.

Greenhouse Experiment

Seedlings were grown in mini trays using the same system and initial procedures as used for the growth chamber studies. At 20 DAS, treatments were randomly assigned to the four mini trays of each block. Treatments were (a) control, (b) water stress, (c) ABA top and (d) ABA low. Control plants were those that were maintained between 50 to 25 % of water holding capacity. Water stressed plants were those that were not irrigated until 85 % of the available water had been removed. 'ABA top' consisted of ABA foliar spray application, and 'ABA low' consisted of root-medium bottom application by flotation. ABA applications were done at 20, 23, and 25 DAS. At these times, 0.1 % v/v Tween 20 and water were applied in the other experimental plots.

Plant samplings were taken at 23, 29, 35, 41, 47 and 53 DAS. Growth measurements and data analysis were done as previously described.

Results and Discussion

ABA had an inhibitory effect on germination and seedling development, and there was a linear increase in number of abnormal seedlings with increases in ABA concentrations (Table 5-1). The mean days of germination (MDG) evidenced a quadratic increase caused by 10^{-5} and 10^{-4} M ABA, with the quadratic root-length reduction being most evident at 10^{-4} M ABA. When ABA was applied to the leaf surfaces 33 and 37 days after seeding, it produced a reduction of root fresh and dry weight and an increase in stem (dry weight) and shoot:root ratio compared to the control (Table 5-2). Shoot:root ratio increased linearly with increase in ABA concentrations.

Based on these preliminary germination and emergence experiments, ABA 10^{-4} M was selected as the critical concentration expected to cause a growth reduction without visible phytotoxic effects when applied to young pepper seedlings.

Germination of tomato seeds was inhibited between $1.5 \cdot 10^{-4}$ and $5 \cdot 10^{-4}$ M (Liptay and Schopfer, 1983). ABA 10^{-4} M caused an osmotic stress, lowering the ability of rape (Brassica napus L.) embryos to absorb water. At 10^{-3} M, ABA completely inhibited germination and seedling growth (Schopfer and Plachy, 1984). For oats seedlings, root length decreased at ABA 10^{-4} M and was completely suppressed at 10^{-3} M (Wightman et al., 1980). It is generally accepted

Table 5 1 Effects of ABA on germination and seedling growth of pepper

ABA concentration (M)	Germination (%)	MDG[y] (days)	Seedlings[x] Normal (%)	Abnormal (%)	Dead (%)	Dry wt (mg)	Root length (mm)
Control	97	4 4	76	16	7	3 4	47
10^{-8}	94	4 3	64	27	10	3 5	46
10^{-7}	96	4 4	63	22	15	3 2	47
10^{-6}	93	4 5	54	32	14	3 2	36
10^{-5}	89	5 1	58	28	14	3 4	33
10^{-4}	26	5 9	27	52	20	3 2	22
			Orthogonal Contrasts				
Control vs others	**	**	**	**	*	NS	**
ABA	L*	Q**	L*	L*	NS	NS	Q**

[x]Data measured after 7 days at 25°C in dark incubator
[y]MDG = Mean days of germination
NS, *, **Nonsignificant or significant F-test at P=0 05 or 0 01 ABA concentration effect was linear (L) or quadratic (Q)

Table 5-2 Shoot and root characteristics of pepper seedlings as affected by ABA [z]

ABA concentration (M)	Stem length (cm)	Stem diameter (mm)	Leaf area (cm^2)	Fresh wt. Root (mg)	Dry wt. Leaf (mg)	Dry wt. Stem (mg)	Dry wt. Root (mg)	Shoot/ root ratio
Control	5 9	1 9	23	147	58	17	10	8 4
10^{-8}	6 1	2 0	23	146	58	19	10	8 5
10^{-7}	6 0	2 0	24	157	61	20	10	8 8
10^{-6}	6 3	2 0	23	139	59	21	9	9 5
10^{-5}	5 9	2 0	23	148	59	21	9	9 1
10^{-4}	5 5	2 0	23	132	60	20	9	10 1
10^{-3}	5 8	2 0	22	101	54	17	7	11 1
			Orthogonal Contrasts					
Control vs. others	NS	NS	NS	**	NS	*	**	**
ABA	Q*	NS	NS	NS	NS	NS	NS	L*

[z]Measurements were done 60 days after seeding (DAS) ABA was applied on the upper leaves at 33 and 37 DAS

NS, *, **Nonsignificant or significant F test at P = 0 05 or 0 01, respectively ABA concentration effect was linear (L) or quadratic (Q)

that ABA increase stomata closing (Raschke, 1975), reducing photosynthesis rates (Mittelheuser and Van Steveninck, 1971) and probably effecting assimilate partitioning to roots.

In the growth chamber experiment, seedlings grown under continuous watering (CW) had a significantly lower shoot:root ratio and higher root growth than those grown with alternate-day watering (AW) (Table 5-3).

The effect of applied ABA on leaf dry weight became apparent at 30 DAS (Fig. 5-1A). Between 26 and 30 DAS, the relative growth rate decreased from 0.060 to -0.025 $g \cdot g^{-1} \cdot day^{-1}$ for plants subjected to CW+ABA and from 0.135 $g \cdot g^{-1} \cdot day^{-1}$ to 0 for plants treated with AW+ABA. A relative growth rate reduction was reported for eggplant seedlings when ABA 10^{-3} M was sprayed onto leaves (Latimer and Mitchell, 1988). During this period, net assimilation rate (NAR) was 0.90 and 1.58 $g \cdot m^{-2} \cdot day^{-1}$ for CW+ABA and AW+ABA treated plants and 4.16 and 5.41 $g \cdot m^{-2} \cdot day^{-1}$ for CW and AW treated plants without ABA. As NAR is considered a physiological index (Evans, 1972), ABA seemed to reduce the photosynthetic capacity of the seedlings.

Inhibition of the leaf dry weight increase due to applied ABA was even greater for seedlings irrigated with continuous watering. Seedlings under this water regime may be more sensitive to applied ABA than AW-treated seedlings, which may have acquired an endogenous increase of ABA levels due to mild stress (Dorffling et al., 1977). Between 30 and

Table 5.3 Shoot and root characteristics of pepper seedlings as affected by watering and ABA treatment (Growth chamber expt.)

Source of[a] variation	Stem diameter (mm)	Leaf area (cm^2)	Dry wt. Leaf (mg)	Dry wt. Stem (mg)	Dry wt. Root (mg)	Shoot root ratio
Treatment (Trt)						
CW ABA	1.8	16.5	56	27	24	3.8
CW + ABA	1.8	15.4	49	26	23	3.6
AW ABA	1.7	16.1	50	24	19	4.1
AW + ABA	1.8	16.9	50	28	21	4.0
			Orthogonal Contrasts			
CW vs AW	NS	NS	NS	NS	**	*
-ABA vs +ABA	NS	NS	*	NS	NS	NS
Water vs ABA	NS	NS	NS	NS	NS	NS
Time						
22	1.3	8.9	33	6	8	4.9
26	1.5	11.5	43	11	12	4.7
30	1.7	17.9	49	17	18	3.7
35	1.8	17.0	51	29	25	3.6
41	2.0	17.9	61	36	32	2.8
48	2.2	24.1	70	57	36	3.6
Significance	Q*	Q**	L**	Q*	L**	C**
			Interaction			
Trt x Time	NS	NS	**	NS	**	NS

[a]CW = continuous watering, AW = alternate watering. ABA = without ABA, + ABA = with ABA. Time in days after seeding (DAS). ABA 10^{-4} M was applied 28, 32, and 37 DAS.

NS, *, **Nonsignificant or significant F test at P = 0.05 or 0.01, respectively. Time effect was linear (L), quadratic (Q), or cubic (C).

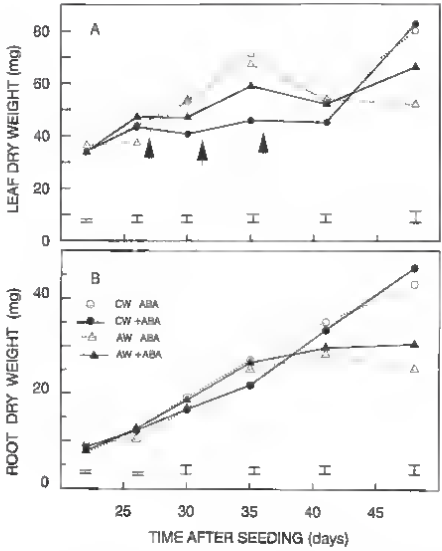


Fig. 5-1. Leaf (A) and root (B) dry weight of papper seedlings in rasponse to watering and ABA 10^{-4} M sprayed on tha leaves (arrows) Vertical bars rapresant LSD at P=0.05. CW= continuous watering, AW= altarnata-day watering, - ABA = without ABA , + ABA= with ABA.

35 DAS a significantly lower leaf dry weight was measured for ABA-treated seedlings in both watering regimes (Fig. 5-1A). At 33 DAS, seedlings treated with ABA evidenced a premature cotyledon abscission, which was 50 and 67% for CW and AW treated seedlings, respectively. An accelerated abscission response was one of the first detected physiological effects of ABA (Addicot, 1983). After 35 DAS, light and/or nutrient limitation and subsequent cotyledon abscission may have caused a net loss in leaf weight, reducing the shoot:root ratio (Table 5-3). Leaf growth of seedlings treated with AW+ABA had a cubic increase which was most evident after 41 DAS. Conversely, AW-ABA treated seedlings had a decline in leaf growth, as previously reported (Watts et al., 1981).

Root dry weight increase was unaffected by water regime or ABA until 35 DAS (Fig. 5-1B). Thereafter, seedlings grown under continuous watering with or without ABA had a linear increase in root growth compared to those under alternate-day watering.

Continuously watered seedlings had a significantly higher number of basal roots with larger basal and basal first-order root diameters than AW-treated seedlings (Table 5-4). Basal roots constitute an important root component of the pepper root system (Leskovar et al., 1989). Root numbers and basal roots were unaffected by ABA. Wightman et

Table 5 4. Root number and root diameter of pepper seedlings as affected by watering and ABA treatment at 48 days after seeding (Growth chamber expt.)

Source of[a] variation	Root number		Root diameter (mm)			
	basals	laterals	basal	basal 1st order	lateral	lateral 1st order
Treatment						
CW - ABA	31	19	0.44	0.29	0.37	0.25
CW + ABA	37	17	0.49	0.32	0.34	0.25
AW - ABA	13	17	0.36	0.22	0.37	0.33
AW + ABA	19	17	0.39	0.25	0.34	0.25
			Orthogonal Contrasts			
CW vs AW	**	NS	*	**	NS	NS
-ABA vs +ABA	NS	NS	NS	NS	NS	NS
Water vs ABA	NS	NS	NS	NS	NS	NS

[a]CW = continuous watering, AW = alternate wareting, - ABA = without ABA, + ABA = with ABA. ABA 10^{-10} M was applied at 28, 32, and 37 days.
NS, *, **Nonsignificant or significant F-test at P = 0.05 or 0.01 respectively.

al. (1980) reported that ABA 10^{-4} M caused a decrease in the number of lateral root primordia in maize seedlings.

In the greenhouse experiment the effect of ABA on total dry weight was not evident until 35 DAS (Table 5-5). At 35 DAS, approximately one week after the last ABA application, ABA-top and ABA-low treated seedlings had a significantly greater leaf dry weight growth reduction as compared with the control (Fig. 5-2A). Interestingly, at 41 DAS, significantly lower leaf dry weight was measured for ABA-top as compared with ABA-low seedlings, suggesting that when ABA was applied onto the leaves, a faster response is expected than when applied directly onto the rooting medium. At 53 DAS, ABA-low treated seedlings had a significantly lower root growth than ABA-top (Fig. 5-2B). This effect is attributed to ABA toxicity.

In these experiments, exogenous ABA applied to the leaves evidenced a transient leaf-weight-increase inhibition, more evident in seedlings grown under continuous rather than alternate-day watering. The major ABA effect was a reduction in the growth of the leaves, as previously reported (Quarrie and Jones, 1977). This is in contrary to the stress-stimulation root growth increase suggested by Sharp and Davis (1979). ABA applied to plants that were continuously watered did not affect root growth (Fig. 5-2B). Fruit size and total yields were unaffected by the ABA and watering treatments (Table 5-6).

Table 5-5 Total dry weight (mg) of pepper seedlings as effected by watering and ABA treatment (Greenhouse expt)

Treatment*	Days after seeding						Significance	r^2
	23	29	35	41	47	53		
Control	11	27	47	59	77	111	Q*	0 91
Water stress	11	24	39	46	61	82	L**	0 88
ABA top	10	25	34	44	66	98	Q**	0 91
ABA low	10	22	33	48	58	69	L**	0 89

*Control seedlings were irrigated at 25% of water holding capacity (WHC) and water stress seedlings at 15% of WHC ABA top = foliar spray application, ABA low = root substrate application ABA 10^{-4} M was applied 20, 23, and 29 days after seeding

**Significant at P = 0 05 or 0 01 respectively Tiss effects were linear (L) or quadratic (Q)

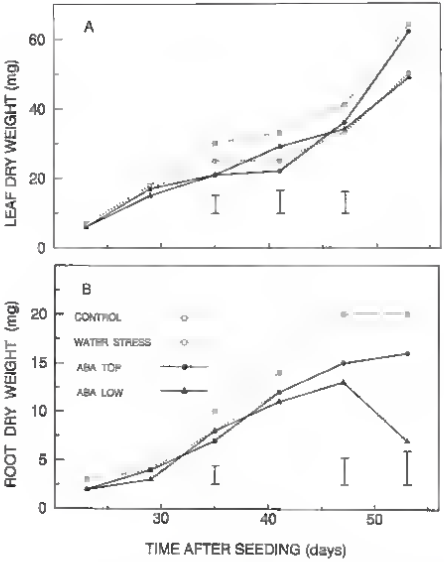


Fig. 5-2. Leaf (A) and root (B) dry weight of pepper seedlings in response to watering and ABA 10^{-4} M spray on the leaves (ABA Top) or applied to the rooting media (ABA Low). Vertical bars represent LSD at P=0.05. ABA was applied at 20, 23, and 29 days after seeding.

Table 5 6 Effects of watering and ABA treatments on pepper fruit yield

Treatment*	Early		Mid		Late	All harvests		
	No 1	Fancy	No 1	Fancy	No 1	No 1	Fancy	Total
	t·ha^{-1}							
CW ABA	4 4	5 2	1 9	2 4	1 6	7 9	7 5	15 5
CW + ABA	5 2	5 4	2 9	3 2	1 5	9 5	8 6	18 1
AW ABA	3 9	7 3	2 9	1 8	1 2	8 0	9 1	17 1
AW + ABA	4 9	6 3	2 9	5 0	1 5	9 2	11 3	20 5
	Orthogonal Contrasts							
CW vs AW	NS	NS	NS	NS	*	NS	NS	NS
ABA vs +ABA	NS	NS	NS	*	NS	NS	NS	NS
Water x ABA	NS	NS	NS	NS	*	NS	NS	NS

Harvests were at 93 (early), 103 (mid) and 117 (late) days after transplanting

*CW = continuous watering AW = alternate watering, ABA = without ABA +ABA = with ABA Transplants were 49 days old at planting ABA 10^{-4} M was applied 28, 32 and 37 days after seeding

NS, *, "Nonsignificant or significant F-test at P = 0 05 or 0 01, respectively

The root dry weight decrease of containerized pepper transplants in response to ABA applied to the rooting medium has not been reported previously. In a maize study where plants were grown in 1000-cm^3 containers, ABA 10^{-4} M sprayed onto leaves or applied into the nutrient solution did not affect root growth, though a leaf necrosis was observed (Watts et al., 1981). This suggests that this method is not beneficial for controlling growth when ABA is applied at 10^{-4} M.

The results of this study underlie the importance of water regime to control growth. ABA can be considered as an antitranspirant to control stomata behavior and reduce water loss. The rate of transpiration was reduced for up to 10 days when ABA 10^{-3} M was applied onto coffee leaves (Mansfield et al., 1978). Further research is needed to determine time and frequency of ABA applications, followed by their affect on growth and fruit yield under diverse field conditions.

Summary

Abscisic acid (ABA) and mild water stress were evaluated on growth morphology and dry weights of pepper (Capsicum annuum L.). Seedlings were subjected to continuous (CW) or alternate-day (AW) sub-irrigation. Based on preliminary germination and seedling tests, ABA 10^{-4} M was used. ABA was sprayed onto leaves 28, 32, and 37 days

after seeding (DAS). Leaf growth was limited by AW and ABA. Root dry weight, basal root number and diameter decreased in AW- as compared to CW-treated seedlings. ABA did not influence root growth and fruit yields.

In a second experiment, when ABA was applied onto leaves (ABA-top), there was a fast leaf dry weight decrease, but root growth was unaffected. ABA applied in the rooting medium reduced root growth compared to the control Water-stress and ABA top-treated seedlings had similar leaf and root growth responses, indicating that ABA mimicked the effects of water stress. The possibility of applying external ABA as a substitute for water stress to control transplant growth in the nursery may be advantageous. ABA applied prior to transplanting could reduce the transpiration of young transplants in order to withstand periods of drought if expected immediately after transplanting

CHAPTER 6

ROOT AND SHOOT GROWTH, DEVELOPMENT, AND YIELD OF TRANSPLANTS AND DIRECT-SEEDED PEPPER

Introduction

Root development and distribution can be critical to plant growth and crop productivity. Early root morphological changes may express an array of root patterns in the field. Pepper (Capsicum annuum L.), a taprooted plant (Weaver and Brunar, 1927), is established in the field by bareroot or containerized transplants or direct seeding, using raw or primed seeds. Primed seeds had faster and earlier germination and root growth in laboratory (Cantliffe and Watkins, 1983; Stoffella et al., 1988a). However, it is unclear if these significant early plant developmental responses are later expressed in the field. Taproot growth of transplants is restricted in containers and the field, promoting the development of basal and lateral roots (Leskovar et al., 1989). Plants from direct field sowing may have a different root pattern because the taproot is undisturbed after seedling emergence. These root morphological differences may ultimately affect fruit development and consequently crop production.

Bell pepper root development at the seedling and vegetative stage has been characterized in growth chamber and greenhouse studies (Nielsen and Veierskov, 1988; Stoffella et al., 1988b). Field studies have not considered root growth in relation to shoot growth (Baumee and Bartz, 1963; Weaver and Bruner, 1927). The spatial distribution of the root system may influence the efficiency by which the soil is exploited. Dry matter partitioning between shoots and roots can indicate the competitive ability of sink regions and the physiological status of the plant.

The present studies were undertaken to determine the effect of pepper transplant production systems and direct seeding on field root and shoot growth and to relate root to shoot growth in terms of dry matter partitioning and allometric relationships

Materials and Methods

Plant Material

Pepper (Capsicum annuum L) 'Jupiter' plants were set in the field with overhead-irrigated transplants (SP1), sub-irrigated transplants (SP2), primed seeds (PS), and untreated or raw seeds (CS). Before sowing in trays, pepper seeds were treated for possible seedborne diseases by immersion in water at 52 °C for 20 min (Shoemaker and Echendi, 1976). This was followed by a surface disinfection with NaOCl at 1 % for 10 min (Fieldhouse and Seeser, 1975).

Transplant Production

The SP1 transplants were grown in plastic greenhouses at Speedling, Inc. at Sun City, Fla. (Lat. 27.4 °N, Long. 82.3 °W). Speedling polystyrene trays with 200 inverted pyramid cells of 2.5 x 7.2 cm (square side length x depth; 18 cm^3) were used. Seeds were sown in a peat-vermiculite-perlite mix (2:1:1, v/v/v) on several dates (Table 6-1). Trays were held in germination chambers at 25 °C and 100 % RH for 3 days, and then placed in greenhouses where they remained until transplanting. After seedling emergence, transplants were watered daily or five times/week by overhead-irrigation until leaching occurred. During each irrigation a soluble fertilizer (20-10-20) was applied at a concentration of 50 mg of N/liter, 12 mg of P/liter, and 40 mg of K/liter. Fertilizer and water were withheld during the last 3 days before field transplanting, for acclimation. The greenhouse was held at 24 °C maximum and 14 °C minimum.

The SP2 transplants were grown in fully automated plastic greenhouses at Speedling Inc., at Bushnell, Fla. (Lat. 28.4 °N and Long 82.5 °W). The trays were held in germination chambers for 3 days at 25 °C and 100 % RH. They were then transferred to greenhouses where they were suspended on metal wires 20 cm above concrete floors. Every two days, the irrigation water was raised to the level of the container, maintained for 30-45 min and then decreased to its original level until the next irrigation. Fertilizer

and plant acclimation were similar to those used for the SP1 transplant. Supplemental fertilizer (10N-52P) was applied at 200 mg of N/liter until leaching at 25 and 35 days after seedling (DAS). The greenhouse was held at 30 °C maximum and 18 °C minimum.

Seed Treatments

Priming was performed by placing the seeds in an aerated solution of polyethylene glycol (mol. wt. 8000) at -0.8 MPa for 4 days at 25 °C in the dark (Cantliffe and Watkins, 1983). After priming, seeds were washed for 5 min with running water, surface-dried using a vacuum filter, and then dried back at 5 °C and 45 % RH to the original 6 % seed moisture. The seeds were stored at 5 °C and 45 % RH until used.

Field Experiments

Transplants and seed treatments were planted at the Horticultural Research Unit, Gainesville, FL. on an Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudultus) in 1988, 1989 and 1990 (Table 8-1). Preplant fertilizer (180N-60P-180K $kg \cdot ha^{-1}$ in 1988 and 1989, and 138N-42P-138K in 1990) was applied broadcast and incorporated in the center of the bed. Beds were fumigated with methyl bromide.chloropicrin (67:33) at 220 $kg \cdot ha^{-1}$ and covered with black (1988 and 1989) or white (1990) polyethylene mulch (0.038-mm thickness). Plants were grown on single raised (20-cm high) beds. Plant spacing was 1.8 m

Table 6-1 Seedling planting and harvesting date of pepper plants established by transplanting or direct seeding.

Year	Planting	Transplants			Direct seeds	
		Seeded	Planted	Harvest DAT[a]	Seeded	Harvest DAS
1988	1	1 March	10 April	72 86 98	10 April	98-111
1989	1	15 Feb	29 March	78 93 98	20 March	102-107
	2	1 March	10 April	98 113	24 March	109-121
1990	1	20 Feb	10 April	78-93 110	22 March	108-118
	2	27 Feb	19 April	68 80-90	30 March	110

[a]DAT = days after planting DAS = days after seedling.

x 0.3 m (between x within rows) in 1988 and 1990 and 1.5 m x 0.3 m in 1989.

Plant water requirements of 25 to 40 mm·week^{-1} were supplied using supplemental overhead irrigation (1988 and 1989) or drip irrigation (1989 and 1990) to keep the soil water potential below 20 centibars at the 20 cm depth. Drip tubing (Netafim, Altamonte Springs, Fl.) was positioned at the soil level, 15 cm to the sides of the plants. Drippers were spaced 30 cm apart, with a drip discharge rate of 2.25 liter·hr^{-1}. In 1990, additional fertilization (8N-12P-8K) was applied weekly through the drip system for 10 weeks using NH_4NO_3, H_3PO_4 and KNO_3 as sources of N/P/K, respectively. Standard pesticides and cultural practices were used (Hochmuth, 1988b). Mean temperatures for the growing seasons were measured (Fig. 8-1).

Plant Samplings

In 1988, destructive plant samplings (1 plant per replication) were initiated 30 days after transplanting (DAT) and 44 days after seeding (DAS). These were continued every two weeks until 88 DAT and 100 DAS. Shoots were excised at the soil surface and oven-dried at 65 °C for 5 days, and dry weights of leaves (LDW), stem (STDW) and fruits (FDW) were measured.

Root samples were excavated using a modified monolith pinboard (Bohn, 1979). A root sampler was constructed, consisting of a 3-sided steel box 10 x 10 cm square and 30

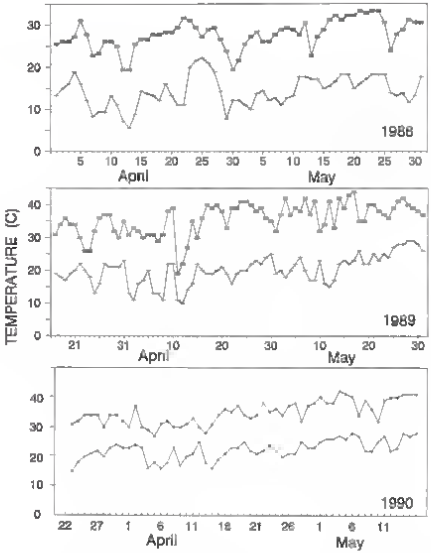


Fig. 8-1. Maximum and minimum air (1988) and soil surface (1989-1990) temperatures during the planting and early growth periods.

cm in length, with two rows of 10-cm length nails to keep the roots in their natural position while soil was removed by washing. Root samples were taken at two soil levels, (A) upper from 0-10 cm; and (B) lower from 10-20 cm, and in three 10-cm wide positions within each depth, one central and two lateral positions adjacent to the central position. A trench face of 0.50 x 0.30 m (length x depth) was dug parallel to the row with the wall then smoothed to a vertical plane. After excavating the soil-root sample, it was gently washed, the bulk of the roots separated from the sampler, and the remaining roots then washed over a 1-mm^2 screen. Root dry weights (RDW) were determined the same as shoot dry weights.

In 1989, root systems from young transplants (2 plants per replication) were partitioned into basal and lateral roots one week prior to planting (T_{-1}), at planting (T_0) and one week after planting (T_1). At each sampling, basal and lateral roots were counted and their length measured using the modified line intercept method (Tennant, 1975), with a 1-cm grid unit. At 50, 70 and 90 days after planting, transplants and direct-seeded plants were partitioned into roots, stems, leaves and fruits, and their dry weights determined as previously described.

In 1990, plant samplings (1 plant per replication) were initiated 30 days after planting and continued every two weeks for 56 days. Roots were excavated as for the 1988

experiment. In the last planting on 26 July, total root mass (1 plant per replication) was partitioned into three components: taproot, basal roots, and lateral roots. Roots were excavated by using a metallic pinboard, consisting of a one-sided steel plate 50 x 30 cm (width x depth) and 0.5 cm thickness, with six rows of 30-cm length nails of 0.5 cm diameter at 5 cm intervals. A trench of 1.0 x 0.5 m (length x depth) was dug around the plant. The soil-root samples were excavated, gently washed, roots were cut, and then separated for each components, and dry weights determined.

Fruit Yield

Fruits were harvested at the mature-green stage (20 plants per replication) on the dates indicated (Table 6-1). Because there were not differences between transplants and between direct-seeded plants at each harvest, the yields were pooled. Fruits were graded into U.S. Fancy (7.5 cm min. dia. and 8.8 cm min. length) and U.S. No.1 (6.25 cm min. dia. and length), counted and weighed (USDA, 1963).

Statistical Procedures

Germination and emergence responses of primed and raw seeds were analyzed by survival analysis (Scott et al., 1984). Field emergence percentages were transformed to arc sine prior to data subjecting them to analyses of variance (ANOVA). Polynomial regression equations were fitted for root dry weight distribution in the soil (Hunt, 1982). In

those cases where the growth was linear, the test of the homogeneity of the regression coefficients ($P \leq 0.05$) was performed and data were pooled when slopes of the linear regressions were nonsignificant. Allometric models between root and shoot (leaves+stems) and between root and top (shoot+fruit) dry weights were determined (Richards, 1981). Slopes of ln-ln regressions (± confidence intervals) were calculated.

During each year, a randomized complete block design with 5 replications per treatment was used. Shoot growth, root growth, and fruit yield data were subjected to ANOVA and orthogonal contrasts. Significant plant establishment x time interactions were partitioned for sampling date.

Results

Seed Emergence

Primed seeds (PS) germinated earlier, with faster germination rates and higher total field emergence than raw seeds (CS) in 1988 (Fig. 6-2) and with higher emergence rates in 1990. Similar emergence responses occurred in 1989, with total emergence pooled across all experiments averaging 57 % for PS and 50 % for CS.

Root Development

The root growth of both overhead- (SP1) and seepage- (SP2) irrigated transplants increased uniformly over time at each soil level and position (central and laterals) when

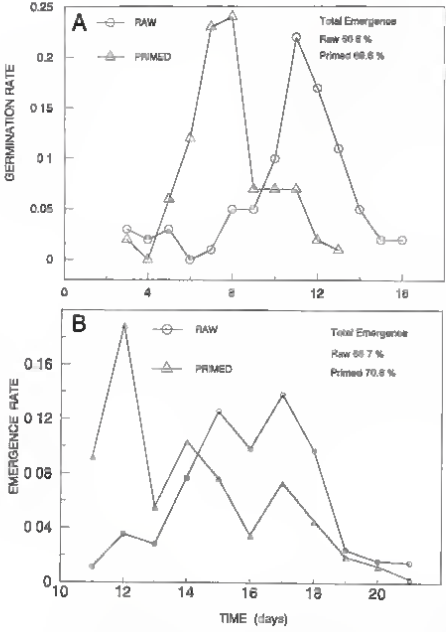


Fig. 6-2. (A) Germination rate of pepper seeds at 15 °C in the laboratory and total field emergence, 1988. (B) Emergence rate of pepper seeds and total field emergence, 1990.

grown under sprinkler irrigation in 1988. Because slopes of the linear equations were similar, root dry weights (RDW) were pooled. In the upper soil level (Fig. 6-3), transplant RDW increased linearly (r^2=0.91) in the central position. This increase was 200 % and 330 % greater than for the right (A3) and left (A1) lateral positions, respectively. The total RDW of transplants increased linearly in each level (Fig. 6-4). The rate of increase was 150 % greater for the upper than for the lower level.

Plants from primed and raw seed had an early exponential root growth increase in the central position, upper soil level (Fig. 6-3,A2) followed by a 'plateau' that was not observed for CS plants. Both types of seeded plants had a similar RDW increase in the upper soil level (Fig. 6-4,A), characterized by a slow growth rate between 44 to 60 days after seeding (DAS) followed by an increased rate of growth thereafter. At the lower soil level (Fig. 6-4,B) the accumulated root dry weight was lower than that for the upper soil level. Root growth of PS steadily increased (r^2=0.84) over time, while that of CS was exponential (r^2=0.91), with a slow growth rate from 44 to 70 DAS followed by increased growth thereafter.

In 1990 when plants were grown under drip irrigation, transplants evidenced a linear root dry weight increase over time for each soil level and position (data not shown). In the upper soil level, RDW of the central position (A2) was

Fig. 6-3. Root dry weight of transplants (TR), primed (PS) and raw (CS) seeded pepper plants in the central and lateral positions at the (A) upper and (B) lower soil levels, 1988. Regression equations for y=root dry weight (mg) and x=time (days) were:

A1: $y=-260.7+10.9x$ ($R^2=0.39$) for TR
$y=1179-49.3x+0.52x^2$ ($R^2=0.84$) for PS
$y=3737-133.8x+1.18x^2$ ($R^2=0.59$) for CS

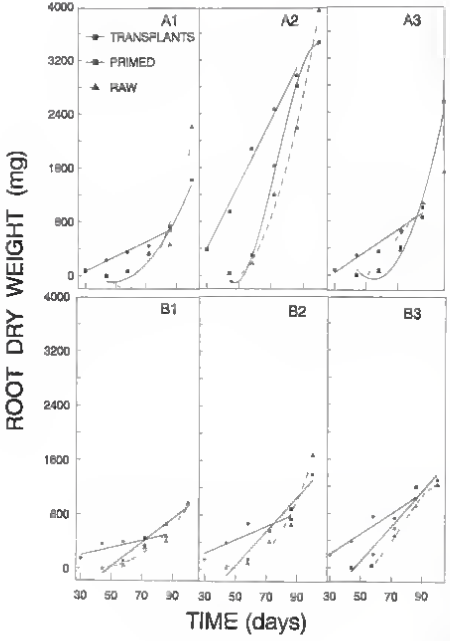
A2: $y=-1035+47.8x$ ($R^2=0.91$) for TR
$y=13702-888.1x+10.71x^2-0.05x^3$ ($R^2=0.97$) for PS
$y=1947-94.7x+1.14x^2$ ($R^2=0.93$) for CS

A3: $y=-433.3+15.79x$ ($R^2=0.84$) for TR
$y=3647-134.9x+1.23x^2$ ($R^2=0.84$) for PS
$y=-1470+28.9x$ ($R^2=0.85$) for CS

B1: $y=84.9+5.3x$ ($R^2=0.30$) for TR
$y=-863+17.7x$ ($R^2=0.83$) for PS
$y=510-23.8x+0.28x^2$ ($R^2=0.83$) for CS

B2: $y=-83.5+9.9x$ ($R^2=0.48$) for TR
$y=-1199+25.2x$ ($R^2=0.80$) for PS
$y=1805-89.3x+0.87x^2$ ($R^2=0.78$) for CS

B3: $y=-235+15.0x$ ($R^2=0.58$) for TR
$y=-1188+25.8x$ ($R^2=0.70$) for PS
$y=5241-253.7x+3.80x^2-0.02x^3$ ($R^2=0.93$) for CS


A1
A2
A3
B1
B2
B3
TRANSPLANTS
PRIMED
RAW
ROOT DRY WEIGHT (mg)
TIME (days)
0
800
1600
2400
3200
4000
30
50
70
90

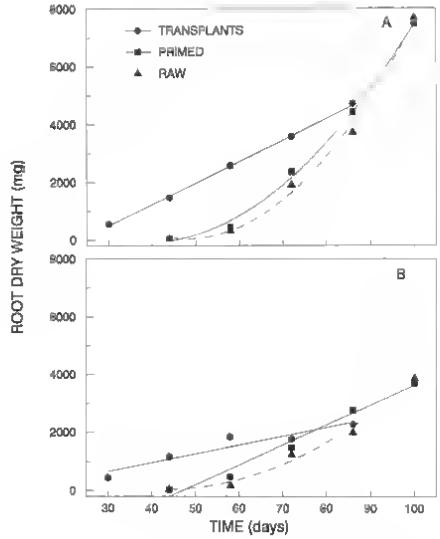


Fig. 6-4. Total pepper root dry weight for the (A) upper and (B) lower soil levels, 1988. Points are means ± SE. Regression equations were: A: $y=-1729+74.4x$ ($r^2=0.91$) for transplants, $y=2735-149.6x+1.97x^2$ ($r^2=0.93$) for primed and $y=6333-263.1x+2.75x^2$ ($r^2=0.84$) for raw seeds. B: $y=-234+30.2x$ ($r^2=0.65$) for transplants, $y=3229+68.5x$ ($r^2=0.84$) for primed and $y=2136-98.6x+1.15x^2$ ($r^2=0.91$) for raw seeds.

3.9-fold and 7.5-fold greater than for the A3 and A1 lateral positions, respectively for SP1 plants, and 4-fold and 5.8-fold greater than for the A3 and A1 positions, respectively for SP2 transplants. The total RDW of transplants increased linearly in each level (Fig. 6-5), the rate of increase was 66 % greater for SP1 than for SP2 transplants. The average root growth increase for transplants was 180 % greater in the upper than in the lower level.

Both PS and CS seeded plants had similar RDW in the upper soil level with a rapid RDW increase after 44 DAS (Fig. 6-5). At the lower soil level, the accumulated RDW was linear over time and lower than that of the upper level. At this level, direct-seeded plants had a 44 % greater linear RDW increase than did transplants.

Root growth of SP1 transplants, between 36 to 50 DAS, was low and increased linearly as compared to the quadratic RDW development of SP2 transplants (Table 6-2). SP1 plants exhibited a larger (22 %) basal root lengths and larger numbers than did SP2 plants (Table 6-3). However, between 50 to 70 DAP, the significant plant establishment x time interaction for RDW (Table 6-4) partitioned for each time, indicated that SP2 plants had a greater RDW than SP1 plants at 70 DAS, with no subsequent differences (Table 6-5).

Under drip irrigation RDW was similar between SP1 and SP2 transplants and between PS and CS seeded plants

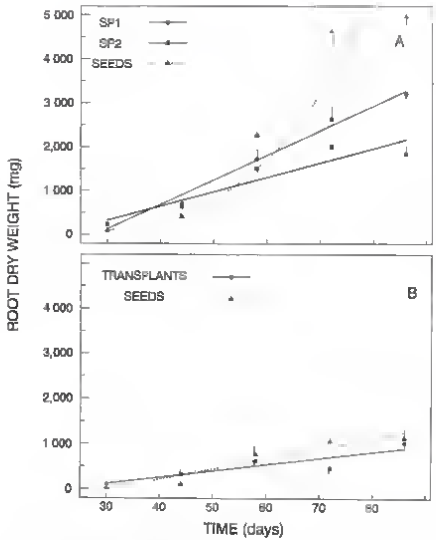


Fig. 6-5. Total pepper root dry weight for the (A) upper and(B) lower soil levels, 1990. Points are means ± SE. Regression equations were:
A: $Y=-1554+56.1x$ ($r^2=0.94$) for SP1, $y=-692+33.8x$ ($r^2=0.74$) for SP2 and $y=14169-940x+18.9x^2-0.11x^3$ ($r^2=0.97$) for seeds.
B: $y=-356+16.0x$ ($r^2=0.79$) for transplants and $y=-681+22.6x$ ($r^2=0.76$) for seedad plants.

Table 6-2 Effects of pepper transplant on early growth (36 to 50 days after seeding) First planting, 1989

Transplant system	Time[a] T_{-1}	T_0	T_1	Significance	r^2
		Root dry wt (mg)			
SP1	16	31	55	L**	0 83
SP2	21	54	62	Q**	0 84
		Leaf dry wt (mg)			
SP1	40	85	132	L**	0 91
SP2	42	87	100	L**	0 68
		Stem dry wt (mg)			
SP1	24	58	116	L**	0 90
SP2	26	66	91	L**	0 91

[a] T_{-1} = 1 week before transplanting, T_0 and T_1 = times at and one week after transplanting

* **Significant at P = 0 05 or 0 01 Time effects were linear (L) or quadratic (Q)

Table 6-3 Effects of pepper transplant on early root growth (36 to 50 days after seeding) First planting 1989

Source of variation	Root length		Root number	
	hazelo	laterels	hazelo	laterels
	(cm)		(No.)	
Transplant system				
SP1	362	254	32	15
SP2	296	491	28	15
	*	**	*	NS
Time[a]				
T_1	142	259	22	11
T_0	293	457	31	15
T_1	552	402	36	16
Significance	L**	Q**	L**	L**

[a] T_1 = 1 week before transplanting T_0 and T_1 = times at and one week after transplanting
NS,*,**Nonsignificant or significant F-test at P=0 05 or 0 01 Time effects were linear (L) or quadratic (Q) *Transplant system x time* interactions were nonsignificant

Table 6-4 Effects of pepper plant establishment on plant growth under sprinkler irrigation First planting, 1989

Source of variation	Plant dry wt. Root	Stem	Leaf	Fruit
	(g)			
Plant establishment (PE)				
SP1 transplant	3 2	8 6	19 4	38 7
SP2 transplant	3 6	7 9	16 9	29 0
Primed seed	3 5	7 1	17 8	19 2
Raw seed	3 7	7 4	17 8	16 2
Contrasts				
Transplants vs seeds	NS	NS	NS	**
SP1 vs SP2	NS	NS	NS	**
Primed vs raw	NS	NS	NS	NS
Time[a]				
50	1 3	2 5	9 8	0 1
70	4 6	7 8	18 1	18 9
90	4 6	12 9	25 9	58 4
Significance	Q**	L**	L**	Q**
		Interaction		
PE x Time	*	NS	NS	*

[a]Time=days after planting
NS,* **Nonsignificant or significant F-test at P=0 05 or 0 01, respectively
Significant time effects were linear (L) or quadratic (Q)

Table 6 5 Effects of pepper plant establishment on root growth under sprinkler irrigation First planting 1989

Plant establishment	Days after planting		
	50	70	90
		Root dry wt (g)	
SP1 transplant	1 6	3 6	4 3
SP2 transplant	1 6	4 8	4 6
Primed seed	1 1	4 7	4 9
Raw seed	1 0	5 5	4 7
Contrasts			
Transplant vs seed	**	*	NS
SP1 vs SP2	NS	*	NS
Primed vs raw	NS	NS	NS

NS,*,**Nonsignificent or significant F test at P=0 05 or 0 01, respectively

(Table 6-6). However, seeded plants exhibited a greater root mass than transplants at 90 DAS.

Basal roots accounted for the greatest proportion (61 %) of the total root biomass of transplants, and lateral roots accounted for the greatest proportion (57 %) of the total root biomass of seeded plants (Table 6-7). Taproots accounted for only 4 % of the root biomass in transplants and 16 % in seeded plants.

Shoot Development

Dry weights of all plant organs from the SP1 treatment increased over time (Fig. 6-6). However, after 60 days, a significant amount of dry matter was allocated to fruits and proportionally less to stems, with no significant change in the allocation to roots and leaves. The latter evidenced constant linear growth increase At 66 DAP, fruit, stem, leaf and root dry matter accounted for 66, 11, 19 and 4 % of the total, respectively, for transplants.

Dry weights of all plant fractions from both primed and raw (Fig. 6-7) seeded treatment increased over time. Fruit dry weight began to increase when LDW and STDW began to decline. Conversely, root weight had a continuous increase more evident after 60 DAS. At the end of the growth period fruit, stem, leaf and root dry matter accounted for 39, 16, 33 and 12 % of the total, respectively, for seeded treatments.

Table 6-6 Effects of pepper plant establishment on root and shoot growth under drip irrigation

First planting 1989

Plant establishment	Root dry wt (g)			Leaf dry wt (g)			Fruit dry wt. (g)		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
SF1 transplant	1 4	3 7	4 8	11 6	12 6	21 7	0 4	33 1	77 5
SF2 transplant	1 5	4 4	4 6	13 5	15 3	18 7	-	30 0	71 2
Primed seed	0 6	3 8	5 6	2 6	14 4	20 2	-	4 1	33 9
Raw seed	0 6	4 2	5 7	2 5	14 4	21 9	-	2 0	39 8
Contrasts									
Transplant vs seed	**	NS	**	**	NS	NS	-	**	**

$^{z}T_1$, T_2 and T_3 are times at 50, 70, and 90 days after planting.
^{y}**, NS Nonsignificant or significant F-test at P=0 01 SF1 vs SF2 and primed vs raw seed contrasts were not significant

Table 6.7 Effects of pepper plant establishment on root growth. Second planting, 1990 [a]

	Root components dry wt.			
Plant establishment	Tap	Basals	Laterals	Total
	(g)			(g)
SP1 transplant	0.32	6.30	1.31	7.92
SP2 transplant	0.38	8.69	1.32	10.39
Primed seed	1.98	1.87	5.71	9.57
Raw seed	2.00	3.49	6.72	12.20
Contrasts				
Transplant vs seed	**	**	**	NS
SP1 vs. SP2	NS	NS	NS	NS
Primed vs raw	NS	NS	NS	NS

[a] Root samples were taken on 26 July 1990 at 106 days after transplanting
NS, ** Nonsignificant or significant F test at P=0.01

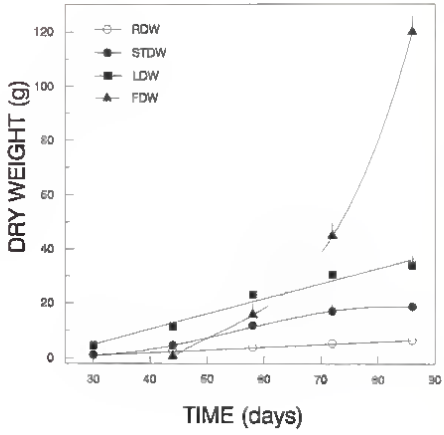


Fig. 6-6. Root (RDW), stem (STDW), leaf (LDW) and fruit (FDW) growth for SP1 pepper transplants in 1988. Points are means ± SE

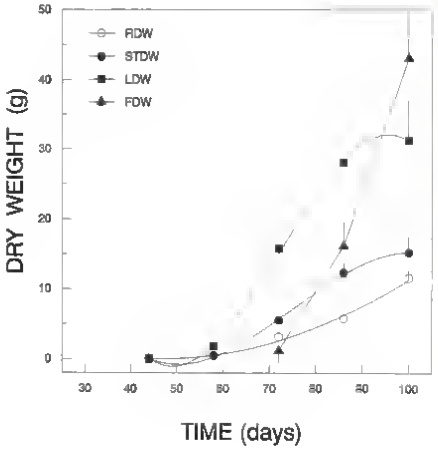


Fig. 6-7: Root (RDW), stem (STDW), leaf (LDW) and fruit (FDW) growth for raw-seeded plants in 1988. Points are means ± SE.

In 1990, under drip irrigation, more dry matter was allocated to fruits for the SP1 transplants 50 DAT (Fig. 6-8,A). There was a linear root (r^2=0.94) and stem (r^2=0.86) growth increase over time, while leaf growth was quadratic (r^2=0.91). The LDW decrease occurred at a time when FDW began to decline as well. At the end of the growth period fruit, stem, leaf and root dry matter accounted for 60, 19, 18 and 3 % of the total, respectively, for transplants.

For primed-seeded plants there was a decline of LDW (cubic, r^2=0.93) and STDW (cubic,r^2=0.93) after 72 days (Fig. 6-8,B), while RDW increased steadily over time (cubic, r^2=0.90). At 86 days, fruit, stem, leaf and root dry weight accounted for 42, 22, 26 and 10 % of the total, respectively, of the seeded treatments.

In 1989, both SP1 and SP2 plants had similar STDW and LDW at planting, and growth trends (Table 6-2) were not changed in the field between 50 to 90 days under sprinkler irrigation (Table 6-4). Shoot growth was similar between SP1 and SP2 transplants, and between primed and raw seeded plants grown under drip irrigation (Table 6-6).

Allometric Relationships

Plants from primed seeds had a significantly higher Kv slope [slope of root against shoot (leaves+stems)] than SP1 transplants (Table 6-8). In both transplant treatments, SP1

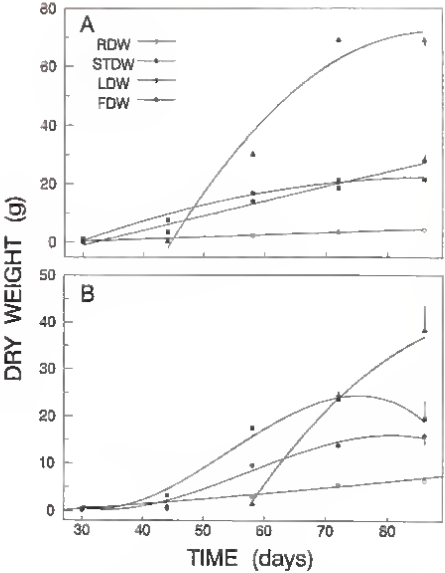


Fig. 6-6. Root (RDW), stem (STDW), leaf (LDW) and fruit (FDW) growth for SP1 pepper transplants (A) and primed seeded pepper plants (B) in 1990. Points are means ± SE.

Table 6-8. Allometric relationship between root against shoot (leaf + stem) and between root against top (shoot + fruit) dry weight 1988 *

Treatment	Kv	t	Kf	t
SP1 transplant	0 765 (±0 090)	0 972	0 516 (±0 068)	0 966
SP2 transplant	0 883 (±0 105)	0 972	0 609 (±0 083)	0 963
Primed seed	0 927 (±0 069)	0 989	0 854 (±0 062)	0 989
Raw seed	0 874 (±0 098)	0 974	0 816 (±0 073)	0 983

*Linear regressions are in the form ln(root d wt)=a+Kv*ln(shoot d wt) or ln (root d wt)=a+Kf*ln(top d wt) where Kv and Kf (± 95% confidence limits) are the slopes and t the regression coefficient (P≤0 05)

Table 6-9. Allometric relationship between root against shoot (leaf + stem) and between root against top (shoot + fruit) dry weight, 1990 *

Treatment	Kv	r	Kf	t
Transplants	0 441 (±0 052)	0 915	0 322 (±0 033)	0 936
Direct seeds	0 563 (±0 053)	0 944	0 492 (±0 029)	0 978

*Linear regressions are in the form ln (root dry wt) = a + Kv ln (shoot dry wt) or ln (root dry wt) = a + Kf ln (top dry wt) where Kv and Kf (± 95% confidence limits) are the slopes and t the regression coefficient (P≤0 05). Dry weights of SP1 and SP2 plants (transplants) and primed and raw seeded plants (direct seeds) were pooled.

(Fig. 6-9) and SP2, the Kf slope [slope of root against top (shoot+fruits)] was significantly different than the Kv slope (Table 6-8).

SP1 and SP2 transplants grown under drip irrigation had the same Kf and Kv slopes. Similarly, for both FS and CS plants the Kf slope was not significantly different than the Kv slope. Therefore, data were pooled (Table 8-9). Direct-seeded plants had significantly higher Kv than transplants. The Kf slope of transplants was significantly different than the Kv slope, but remained the same for the seeded plants

Fruit Yields

Transplants had higher total marketable fruit yield than direct seeded plants in 1988 (Table 8-10). This difference was mainly due to greater amounts of No.1 fruits, which represented 90 % of the total. Yields were similar within the transplants and within the direct seeding group.

For the 1989 first planting, transplants (SP1 and SP2) and direct seeded plants (FS and CS) grown under sprinkler irrigation had similar total, fancy and No.1 fruit yields; however, SP1 produced more fancy fruits than did SP2 transplants (Table 6-11). Under drip irrigation, transplants and direct-seeded plants also had similar total and No.1 yields, but transplants exhibited a lower fancy fruit yield than direct seeded plants (Table 6-11).

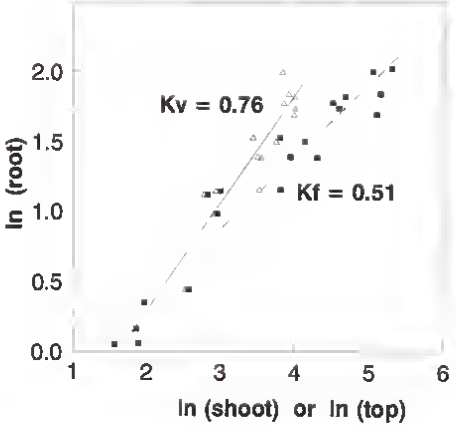


Fig. 6-9. Allometric relationship between root and shoot dry weight (open triangle) and between root and top (shoot+fruit) dry weight (solid square) for SP1 pepper transplants, 1988. Kv is the slope of root against shoot, and Kf is the slope of root against top.

Table 6-10. Effects of pepper plant establishment on fruit yield and number/plant, 1988 [a]

Plant establishment	Fancy	No. 1	Total
		Yield ($t \cdot ha^{-1}$)	
SP1 transplant	2.8	21.9	24.7
SP2 transplant	2.5	22.1	24.6
Primed seed	0.1	9.4	9.5
Raw seed	0.0	8.4	8.4
Contrast			
Transplant vs. seed	**	**	**
SP1 vs. SP2	NS	NS	NS
Primed vs. raw	NS	NS	NS
		Fruit number/plant	
SP1 transplant	0.6	6.9	7.5
SP2 transplant	0.5	6.9	7.4
Primed seed	0.1	3.8	3.8
Raw seed	0.0	3.7	3.7
Contrast			
Transplant vs. seed	**	**	**
SP1 vs. SP2	NS	NS	NS
Primed vs. raw	NS	NS	NS

[a] Minimum fruit diameters were 7.5 cm (fancy) and 6.2 cm (No. 1). Data was pooled across three harvests.
[b] Significant F test at P = 0.01

Table 6 11 Effects of pepper plant establishment on fruit yield and number/plant First planting 1989 [a]

Plant establishment	Sprinkler irrigation			Drip irrigation		
	Fancy	No 1	Total	Fancy	No 1	Total
			Yield ($t \cdot ha^{-1}$)			
SP1 transplant	4 6	10 7	15 2	2 5	12 7	15 2
SP2 transplant	2 4	9 2	11 6	2 1	9 4	11 4
Primed seed	3 9	10 9	14 9	1 1	9 9	11 0
Raw seed	3 9	11 1	15 0	0 9	9 0	10 0
Contrasts						
Transplant vs seed	NS	NS	NS	**	NS	NS
SP1 vs SP2	NS	NS	NS	NS	NS	NS
Primed ve raw	NS	NS	NS	NS	NS	NS
			Fruit number/plant			
SP1	0 9	3 1	4 0	0 5	4 2	4 7
SP2	0 5	2 9	3 4	0 4	3 0	3 4
Primed	0 7	3 7	4 4	0 2	3 5	3 8
Raw	0 8	3 9	4 6	0 2	3 6	3 9
Contrast						
Transplant vs seed	NS	NS	NS	*	NS	NS
SP1 vs SP2	*	NS	NS	NS	NS	NS
Primed ve raw	NS	NS	NS	NS	NS	NS

[a]Minimum fruit diameters were 7 5 cm (fancy) and 6 2 cm (No 1)
NS, *, **Nonsignificant or significant F test at P = 0 05 or 0 01, respectively

For the 1989 second planting, transplants had similar fruit yields than direct seeded plants grown under sprinkler and drip irrigation (Table 6-12). However, within the transplant group, fancy fruit yield was higher for SP2 plants, than for SP1 plants, and for PS than CS within the seeded-plant comparisons under sprinkler irrigation. Conversely, under drip irrigation SP2 plants had fewer fancy fruits than SP1 plants.

In 1990, transplants exhibited significantly higher total, fancy, and No.1 fruit yields than did direct seeding for both plantings (Table 6-13). In the first planting SP2 had higher total and fancy fruit yield than SP1, while fruit yields were unaffected by priming.

Discussion

Transplants produced with either overhead and seepage irrigation had similar root growth in 1988. The greater root-mass allocation in the upper soil layer (Figs. 6-2 and 6-3) in transplants may have resulted by root morphological changes prior to field establishment. Under greenhouse conditions, transplant root growth patterns are normally dependent on conditions of water, light, fertility and physical stress imposed by the container. These factors usually alter normal taproot and lateral root growth, thereby promoting the branching of new or higher order laterals. In addition, overhead irrigation provides a

Table 6-12 Effects of pepper plant establishment on fruit yield and number/plant Second planting, 1989 [a]

Plant establishment	Sprinkler irrigation			Drip irrigation		
	Fancy	No. 1	Total	Fancy	No. 1	Total
			Yield (t·ha⁻¹)			
SP1 transplant	2.3	14.1	16.4	3.9	11.6	15.5
SP2 transplant	4.9	14.2	19.1	1.2	11.9	13.0
Primed seed	4.7	13.1	17.7	1.4	13.6	15.1
Raw seed	2.3	11.1	13.4	3.0	9.2	12.2
Contrasts						
Transplant vs seed	NS	NS	NS	NS	NS	NS
SP1 vs. SP2	*	NS	NS	*	NS	NS
Primed vs raw	*	NS	*	NS	**	NS
			Fruit number/plant			
SP1	0.5	4.5	5.0	0.9	3.9	4.8
SP2	1.1	4.4	3.3	0.3	4.1	4.4
Primed	0.9	4.3	3.4	0.3	5.6	5.9
Raw	0.4	4.1	4.5	0.6	3.6	4.2
Contrasts						
Transplant vs seed	NS	NS	NS	NS	NS	NS
SP1 vs SP2	**	NS	NS	*	NS	NS
Primed vs raw	*	NS	NS	NS	**	*

[a] Minimum fruit diameters were 7.5 cm (fancy) and 6.2 cm (No. 1). NS, *
[b] Nonsignificant or significant F-test at P = 0.05 or 0.01 respectively

Table 6-13 Effects of pepper plant establishment on fruit yield and number/plant. Early and late plantings, 1990 [a]

Plant establishment	Early planting			Late planting		
	Fancy	No. 1	Total	Fancy	No. 1	Total
			Yield ($t \cdot ha^{-1}$)			
SP1 transplant	0.5	19.7	20.1	1.4	14.5	15.9
SP2 transplant	2.1	22.7	24.9	1.1	14.4	15.5
Primed seed	0.0	12.0	12.0	0.0	11.5	11.5
Raw seed	0.0	13.1	13.1	0.0	10.5	10.5
Contrasts						
Transplant vs seed	**	**	**	**	**	**
SP1 vs. SP2	**	NS	*	NS	NS	NS
Primed vs. raw	NS	NS	NS	NS	NS	NS
			Fruit number/plant			
SP1	0.1	8.5	8.6	0.3	6.2	6.5
SP2	0.5	8.5	9.0	0.2	6.4	6.6
Primed	0.0	6.5	6.5	0.0	5.1	5.1
Raw	0.0	6.8	6.8	0.0	5.0	5.0
Contrasts						
Transplant vs seed	**	**	**	**	**	**
SP1 vs. SP2	**	NS	NS	NS	NS	NS
Primed vs. raw	NS	NS	NS	NS	NS	NS

[a] Minimum fruit diameters were 7.5 cm (fancy) and 6.2 cm (No. 1)
NS, *, **Nonsignificant or significant F test at $P = 0.05$ or 0.01, respectively

uniform moisture levels around the hypocotyl, promoting early basal root growth, as compared to the SP2 transplants grown under the soapaga irrigation.

The root mass allocation in the upper soil layer for SP1 transplants (Fig. 6-4) may be attributed to the affects a greater basal root growth between 50 to 70 DAP The higher basal root length and number for SP1 plants prior to and early after planting (Table 6-3) provides a greater ability for water absorption and nutrient acquisition than SP2 plants The importance of basal roots during early ontogeny has been reported for peppers (Stoffella et al. 1988b). It can be argued that pepper transplants may have a time of intense basal root growth from emergence to mid development (approximately 50 to 70 DAP). Subsequently, root growth compensation is likely to occur, minimizing the initial differences in root-component dry weights (Table 6-7).

Pepper transplanth hed a low root development in the 10-20 cm soil layer for much of the growing season. This response may be associated with early taproot modification in the greenhouse prior to planting. Also, root growth might have been affected by cultural practices such as irrigation and water distribution (Goldberg et al., 1971), nutrients (Miller et al., 1979) and mulch (Locascio et al., 1985).

The early germination responses for primed seeds (Fig. 6-2) in 1988 did not affect field root growth in the upper soil level (Fig. 6-4,A). For pepper, after seed germination, tap root elongation is followed by emergence and growth of basal roots originated from the hypocotyl (Stoffella et al., 1988b). Basal roots may contribute to more than 40 % of the total root mass (Leskovar et al., 1989) Therefore, it may be possible that growth and development of basal roots in the upper soil layer may have overridden any germination and early root growth differences. At the lower soil level, root growth of seeded plants was more variable than for the upper level. The linear root growth of PS plants contrasted to the exponential root growth of the CS plants. This differential response is difficult to explain. Seed priming promotes early radicle protrusion and associated taproot elongation. Seeding in stressful conditions may have affected the taproot growth of PS rather than CS seedlings, thereby altering subsequent lateral root growth and branching.

In 1990 under drip irrigation, the early emergence rates for PS (Fig. 6-2,B) did not effect the subsequent field root-growth distribution (Fig. 6-5). Both seeded treatments had similar trends in the upper and lower soil layers, as in 1988. Total root dry weight was also similar for both PS and CS plants, and was not affected by irrigation systems (Tables 6-5, 6-6).

Over all seasons, the uniform root growth of transplants contrasted with that of the seeded plants, which had early slow growth followed by a sharp increase that eventually exceeded the root mass of the transplants (Fig. 6-4). Upon seeding, rapid taproot elongation occurred and basal and lateral roots increase after a reduction in the rate of taproot elongation (Stoffella et al., 1988b). The slow growth for seeded plants is attributed to a greater taproot growth. Taproot contributed to 18 % of the total root biomass for seeded plants, compared with only 4 % of the total root weight for the transplants. Lower lodging resistance thus can be expected for transplants than for direct-seeded plants.

The increase in fruit growth without affecting root growth of transplants and direct seeded plants is a finding that is in contrast to those reported in other studies, where pepper fruit growth increase was correlated to root growth decrease (Clapham and Marsh, 1987; Nielsen and Veierskov, 1988). However, in the first study pepper plants were grown without mulch on a silty soil, while in the second study, plants were grown hydroponically. In our sandy soils, the use of mulch and either sprinkler or drip irrigation are important components to reduce stress in the root environment. The larger root growth rate for seeded plants at the end of the growing season could be a response

to senescence and reduction in fruit sink demand, which was not as evident for transplants.

Growth coordination between roots and shoots exists when their respective (dry weight basis) logarithms are linearly related (Richards, 1969). However, the growth of fruits may compete with the growth of roots for nutrients and with shoots for photosynthates, thus altering the growth relationships. For transplants, the allometric relationships (Tables 6-8 and 6-9) suggested that the coordination of growth between roots and other plant organs changed after fruit set, as previously reported for pepper plants grown hydroponically in a greenhouse (Nielsen and Veierskov, 1988). The lack of significant difference between the Kv and Kf slopes for primed and raw seeded treatments indicates that growth of roots and shoots did not change after fruit set as in the case of tomato (Richards, 1981). A reduced fruit sink strength or utilization of assimilates for root growth or other processes that affect dry weight changes may have mediated such a response.

In 1988, transplants had 1.8-fold larger marketable fruit yield than direct-seeded plants with an average of 7.5 fruits/plant as compared with 3.8 fruits/plant for direct- seeded plants. In this season, both transplants and direct seeded plants were planted on 10 April. The expected lack of earliness in seeded plants was not compensated in later harvests. In 1989, direct-seeded plants were

established on 20 and 24 March, 9 and 17 days prior to transplants (Table 6-1). This time, fruit yields were compensated in later harvests, producing similar yields to transplants. In this experiment, transplants were affected by adverse conditions such as sandblasting and severe winds that occurred immediately after planting on 29 March. The lower fancy fruit yields for SP2 transplants in 1989 can be associated with plant condition early in development. SP2 plants were shorter (10.4 ± SE 0.1 cm), with lower shoot:root ratio (2.9 ± 0.3) than SP1 plants which were 13.7 ± 0.5 cm long with a shoot:root ratio of 4.9 ± 0.4. In addition, SP2 transplants had lower root, leaf and stem growth rates than SP1 plants (Table 6-2). In 1990, direct-seeded plants were established on 22 and 30 March, 19 and 20 days prior to transplants. Transplants had 78 % and 43 % more fruit yields than direct-seeded plants in the first and second plantings, respectively. Within the transplant group, SP2 plants had a 24 % higher total yield and more fancy fruits than SP1 transplants. This response could be associated with the superior SP2 transplant condition at transplanting, with lower shoot:root ratio (4.9 vs. 5.4) and higher total RDW (35 vs. 24 mg), basal RDW (21 vs. 16 mg) and lateral RDW (15 vs. 9 mg) than for the SP1 plants.

Although these experiments were not designed to select a planting date and irrigation system, in general, highest

yields were obtained for transplants planted on 10 April and for direct seeds when planted between 22 to 24 March. Although growth trends were independent of irrigation, it appeared that both transplants and direct-seeded plants produced relatively more fruit yield when grown under sprinkler irrigation. However, fruit yields were improved under drip irrigation in 1990, when fertilizer was applied through the drip system.

In this study, pepper transplants had uniform root growth, while direct-seeded plants had variable root growth with only small growth differences between primed and raw-seeded treatments. Comparing the direct-seeded plants and transplants, the latter exhibited early root modification and greater fruit sink demand and had superior plant growth and productivity compared to direct-seeded plants.

Summary

The objectives of this work were to assess and describe pepper (Capsicum annuum L.) root distribution in the soil profile and to relate root to shoot growth. Plants were field-grown from transplants produced with either overhead or seepage irrigation, or from direct seeding using either primed or raw seeds, in three years. Drip and sprinkler irrigation were used. Dry weights were determined at frequent intervals beginning after planting. Root growth

was measured at two soil levels, 0-10 cm and 10-20 cm and in three 10-cm wide positions within each level. Transplants and direct seeded plants had 165 and 100 % respectively greater root mass in the upper than in the lower soil level. Root growth increase was linear over 56 days for transplants, while root growth for direct-seeded plants exhibited a lag phase of approximately 14 days, with a sharp increase thereafter. At the end of the growth period, fruit, stem, leaf and root dry weight accounted for 63, 15, 18, and 4 % of the total for transplants and 40, 19, 30, and 11 % of the total for direct-seeded plants. Tap, basal, and lateral roots accounted for 4, 81, and 15 % of the total for transplants and 18, 25, and 57 % of the total for direct- seeded plants. The coordination of growth between root and shoot changed after fruit set only for transplants, indicating that transplants exhibited greater fruit sink demand and fruit production than seeded plants.

CHAPTER 7

SUMMARY

Yields of field grown fresh market tomatoes were related with transplant production techniques, regardless of season of the year. Transplants produced with overhead irrigation (SP1) consistantly maintained uniform shoot and root growth, while those grown with sub-flotation (wet/dry) irrigation (SP2) evidanced an arrested shoot growth and reduced shoot:root ratio, particularly when severe hardening was imposed as in the fall of 1987. Early in ontogeny, basal roots were more characteristic for SP1 than for SP2 transplants. Conversely, SP2 and SP3 plants, also grown with the flotation system except that the water plus nutrients were in the bed, had more lateral roots. This response appears to be characteristic for plants growing with the sub-flotation method. If transplants are grown for longer periods of time or under high water stress, their lateral roots, particularly root apicals, are more likely to be subjected to early suberification and aging. This can affect water absorption and nutrient transport, most likely calcium (Troughton, 1981).

Uniform root and shoot growth prior to and following transplanting seems to be of importance for shoot growth in

the field. However, after 120 days total root growth (dry weight basis) of both transplants and direct seeded tomato plants was similar and accumulated 73% of the total root biomass in the upper 10 cm of soil.

Tomato transplants had more uniform growth, better plant survival, and achieved earlier and higher crop yields than plants established by direct seeding. In general, transplants have a lower plant establishment cost than direct seeding. Additional costs for direct seeding includes extra-seed costs, thinning, weed control, and the requirement for more sprays and irrigations, since they are in the field longer than transplants.

The growth of SF2 tomato transplants was evaluated in response to age in four field experiments under drip and sub-seepage irrigation. In spring, older transplants had more shoot and root growth two weeks after transplanting. Thereafter, growth of 4-, 5-, and 6-week-old transplants was similar. In the fall, shoot growth increased linearly with increasing transplant age at planting, but not thereafter. These trends were independant of field irrigation method. Total yield and early yield were not different among transplant-age treatments. Younger transplants had initially higher chlorophyll a+b and chlorophyll a/b ratio, specific leaf area values and greater relative growth rates than older transplants. Therefore, no improvement in yield was obtained using the older transplants. Younger

transplants might be used to achieve rapid seedling establishment with minimal transplant production costs. Younger transplants have a high rate of root growth and might avoid high temperatures generated by the mulch, provided water is not limiting to affect turgor. However, under severe post-planting water stress, older and hardened transplants might survive and resume growth better than young plants if the stem is partly suberized.

Tomato transplant growth was also affected during handling and maturity. When 35-day-old transplants were kept at 20/2é°C in trays (Not Pulled) at 65é plants·m^{2} or packed in boxes (Pulled) at 2350 plants·m^{2} shoot and root growth decreased as storage time increased from 1 to 3 days. Pulled transplants evidenced a significant reduction in extra-large fruit compared with those transplants kept in trays. Consideration should be given to minimize the effects of pulling and packing young transplants. If planting is delayed beyond two days, storage at lower (e.g. é°C) than ambient temperatures would be desirable. Shoot and root growth of 45-day-old Not Pulled and Pulled transplants was also influenced by storage from 0 to é days at 5 and 15°C. The major leaf and root growth changes occurred after 4 days of storage. At both temperatures Pulled transplants had longer stem length, more stem weight, more specific leaf area, higher shoot:root ratio, and lower root dry weight than Not Pulled transplants. Pulled plants

also had a higher ethylene evolution than Not pulled plants when stored at 5°C. Not Pulled 45-day-old transplants maintained superior shoot and root characteristics as compared with Pulled transplants. Transplant storage temperatures should be selected to avoid the possibility of chilling injury and physiological disorders that may be expressed in the plant or fruit after transplanting, such as cutfacing. This research should be extended to evaluate the effects of prolonged storage conditions on early and total fruit yields at locations other than Florida.

Mild water stress, and abscisic acid (ABA) used as a water stress substitute affected pepper seedling growth. Exogenous ABA applied to the leaves had a transient leaf weight-increase inhibition, more evident in seedlings grown under a continuous rather than alternate-day watering. The major ABA effect was leaf growth reduction without affecting root or final fruit growth in the field. ABA can be considered as an antitranspirant to control stomata behavior and reduce water loss. The possibility of applying external ABA as a substitute for water stress to control transplant growth in the plant nursery may be advantageous. ABA applied prior to transplanting could reduce the transpiration of young transplants in order to withstand periods of drought, if expected immediately after transplanting. Further research is needed to determine

times and frequency of ABA applications, followed by their effect on growth and yield in the field.

Root growth of SP1 and SP2 pepper transplants was uniform as compared with the variable growth from primed and raw-seeded plants. The latter evidenced an early slow growth followed by a sharp increase that eventually exceeded the root mass of the transplants. The initial low root growth rates for seeded plants are attributed to greater dry matter allocation to taproot growth which contributed to 18% as compared with 4% of the total root weight for the transplants. The larger root growth for seeded plants at the end of the growing season may be in response to senescence and reduction in fruit sink demand, not as evident for transplants. Growth between roots and other plant organs changed after fruit set for transplants but not for direct-seeded plants, suggesting that fruits from direct-seeded plants are relatively weak sinks and compete for assimilates with root growth and other processes that affect dry weight changes.

The sub-flotation transplant production system appears to be more conducive to reduce shoot growth, increase root growth, and reduce shoot:root ratio than the overhead irrigation system. Seedlings growing under the flotation method may have a water potential gradient, high at the surface and low at the bottom of the root zone, where high moisture levels promote lateral root growth. In addition,

salts tend to accumulate in the surface increasing the water potential in the hypocotyl region. This environment may cause a transient inhibition of basal root development and suberification of those already present, restricting shoot growth. The latter was found to be highly correlated with basal roots in pepper seedlings (Leskovar et al., 1989). Cultural practices such as watering and fertilization during the transplant production should be adjusted to produce a plant with a shoot:root ratio of 4 to 5. Plants with high (> 6) or low (< 3) shoot:root ratios are more likely to have a lag-time following the planting period.

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